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NAVAL POSTGRADUATE SCHOOL
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THESIS

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A Q-GERT MODEL AND ANALYSIS OF THE
COMMUNICATIONS IN A MECHANIZED BRIGADE
COVERING FORCE

by

9 Master's thesis

10 Henry Charles/Cobb, Jr.

11 March 1979

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Thesis Advisor: A. Schoenstadt

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⟶ The purpose of this thesis is to determine if the Queuing Graphical Evaluation Review Technique (Q-GERT) can accurately model tactical military communications in a manner which can be used and understood by managers who have little computer expertise. Q-GERT is a FORTRAN-based analysis package which models networks consisting of events (nodes) and activities (arcs).

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#20 - ABSTRACT - CONTINUED

The communications for a mechanized brigade covering force is easily modeled using Q-GERT symbolism and user written FORTRAN inserts; however, a manager must be proficient in FORTRAN and have access to the 1000 node/1000 arc Q-GERT package to accurately implement this model.

The conclusion of this thesis is that Q-GERT is a flexible modeling technique which should prove to be a valuable managerial tool for the military manager when the larger Q-GERT package is used.

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by

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B.S., University of Montana, 1970

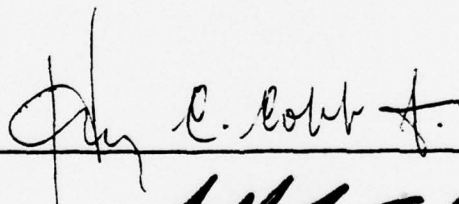Submitted in partial fulfillment of the
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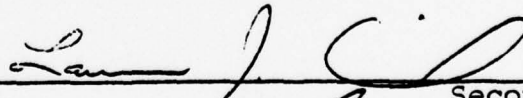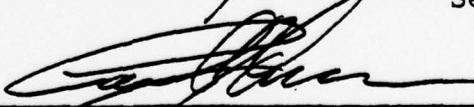

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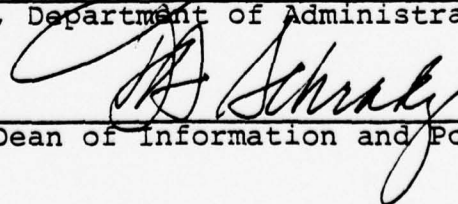
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ABSTRACT

The purpose of this thesis is to determine if the Queuing Graphical Evaluation Review Technique (Q-GERT) can accurately model tactical military communications in a manner which can be used and understood by managers who have little computer expertise. Q-GERT is a FORTRAN-based analysis package which models networks consisting of events (nodes) and activities (arcs).

The communications of a mechanized brigade covering force is easily modeled using Q-GERT symbolism and user written FORTRAN inserts; however, a manager must be proficient in FORTRAN and have access to the 1000 node/1000 arc Q-GERT package to accurately implement this model.

The conclusion of this thesis is that Q-GERT is a flexible modeling technique which should prove to be a valuable managerial tool for the military manager when the larger Q-GERT package is used.

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I. Q-GERT INTRODUCED

A. INTRODUCTION

Analysts are frequently involved with determining the behavior of a system under the influence of various internal and external variables. One approach to obtaining information about system behavior is to physically expose the system to the desired influences and then observe its behavior. This is often not feasible for a variety of reasons.

The process of collecting, translating and interpreting data from an actual system is a labor intensive and involved endeavor. A test unit must be properly trained, transported to the exercise area, equipped with measuring devices and closely monitored even though the gathering of data and the monitoring of a unit may completely negate the "realism" the analysts are trying to simulate. An alternative to this costly and time consuming method of analysis is to model the critical components of the system and conduct analysis upon the model rather than the whole system. This alternative is usually less costly and more time conserving than the former. A model, however, is only an approximation which becomes a more accurate representation of the actual system with the increasing number and detail of the variables con-sidered in the model. The ability of the model to factually replicate a real system is, therefore, dependent upon these essential variables and the modeling technique. The

credibility of the model is, likewise, dependent upon the simulation prowess of the author and the flexibility in the modeling techniques selected.

Simulation techniques are extremely useful tools for the analysis of communication systems. A variety of agencies, military and civilian, rely upon simulation to enhance the analysis process [1]. Modeling is used in many settings, from the determination of communications requirements through system design, operations analysis and system optimization [2]. The individual who chooses to model communication networks quickly learns that there are nearly as many valid simulation techniques as user agencies. This thesis employs a very contemporary modeling technique called Q-GERT (Queuing Graphical Evaluation Review Technique) which was copyrighted in 1977 by A. Alan B. Pritsker and Associates of Purdue University [3].

The purpose of this thesis is to determine if Q-GERT can accurately model communications in a manner which can be used and understood by managers who have little computer expertise. This thesis will be concerned with exploiting the flexibility of the Q-GERT technique while maintaining realism in the communications system modeled. A task force organized mechanized brigade covering force has been selected to size the communications system and to provide a tactical scenario which provides the necessary demands on the communications network. The Forward Deployed Force

Operations Instruction from the Command and General Staff
College, Ft. Leavenworth, Kansas [4], shall be used to
identify the units of the task force and to place the unit in
a tactical environment. Three communication methods, including
simplex radio teletype, voice FM-radio and courier "pouch"
will be modeled using Q-GERT. Only the communications
between battalions and from the battalion to the brigade
will be modeled in this thesis, although a study of a reso-
lution lower than battalion is possible but beyond the scope
of this study.

B. Q-GERT, A COMPUTER MODELING TECHNIQUE

Q-GERT is a FORTRAN-based analysis program which
approximates the concepts of PERT (Project Evaluation Review
Technique). PERT models projects consisting of sets of
activities. Q-GERT augments PERT with the additional capa-
bility of modeling queuing and decision functions in a
graphical form. This characteristic enables the user to
directly translate the graphical representation of the
system into code for computer analysis. Q-GERT also has the
capability of modeling systems that operate under the influ-
ences of risk, random and system unique procedural variables
[5]. Graphic representation, the capability of modeling
queuing and decision functions, and the flexibility of
modeling a variety of procedural variables are the reasons
behind the selection of Q-GERT as the analysis program to
model and analyze the communications of a tactical combat
unit.

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The communications topology is described by a network of events (nodes) and activities (arcs). Q-GERT provides a variety of nodes which could represent queues, assembly points, and decision points within the communication networks. Messages or transactions are transferred from node to node via arcs which are easily modified to adapt to a variety of situations. Q-GERT allows the analyst to access sampling distributions, decision rules and branching conditions to create, modify and destroy messages as they traverse the communications network. The routing of transactions through the system is governed by the use of probabilistic and deterministic branching, assembly, and queuing methods using ranking rules which are formulated by the analyst.

The Q-GERT analysis program provides the necessary flexibility to model most network contingencies. However, when standard Q-GERT symbols and procedures are inadequate to allow the modeling of a certain situation, the user may develop user written programs. These user functions are written in FORTRAN and are generally used when the user encounters a complex system which standard Q-GERT procedures inefficiently or inaccurately represent. The approach of this thesis was to employ as much as possible only the functions available in the Q-GERT program and avoid whenever possible writing user-function FORTRAN inserts. As will be discussed, user-functions were required to model situations

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because utilizing only Q-GERT functions resulted either in a communications model too complicated or in a relationship inaccurately modeled.

C.   SAMPLE OF A Q-GERT MODEL

The examination of a trivial network consisting of six nodes and seven arcs will introduce the reader to some of the essentials of Q-GERT. This network, depicted in Figure 1, models a one-channel simplex communications network of limited capacity. (Appendix A includes a summary of basic Q-GERT symbols.) The node identification numbers appear inside and at the right of the circles and shapes. These nodes represent sequentially a source, a queue, a decision point, another decision point and two sinks. The activity identification numbers are shown in squares adjacent to the arcs. These activities represent branches that route transactions or individual messages through the network.

At "time zero" node one is said to be "released" and a message is generated at this node. Branch 1 schedules the arrival of the next message to the network. In this model, one message is generated each minute. Each newly-generated message is assigned an attribute value as indicated in the center portion of the node. The notation "1 NO 2" signifies that attribute one receives a value from the normally distributed population which has a mean and standard deviation listed in parameter set two. Q-GERT provides the user with twelve probability distributions from which a variety

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AN EXAMPLE Q-GERT NETWORK
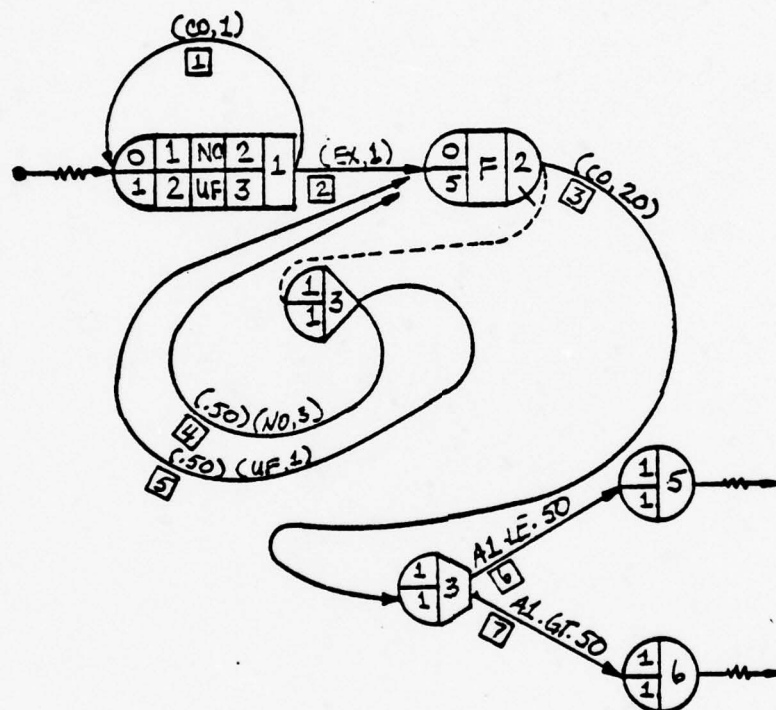
FIGURE 1

of situations may be modeled. Parameter sets are included as part of the input information in the Q-GERT program. For the purpose of this example network, it is assumed that attribute one represents the message length and that a message of 50 words or less will receive different treatment within the defined topology.

The notation "2 UF 3" signifies that attribute two receives a value assignment computed in a user function. User functions are FORTRAN inserts written by the user which model complicated situations. Appendix B discusses the application of user functions. For the purposes of this example, it is assumed that attribute two is the time a message entered the network.

Node 1 is the start node for activity one and activity two. The message that was generated at time = 0 is duplicated; one transaction returning to node one with a one minute time delay and the second transaction advancing to queue node two with a time delay determined by a random sample from the exponential distribution having parameters defined in parameter set one. After a one minute delay, the message which returns to node one causes a second random sampling of the normal distribution with parameter set two, the reassignment of this value to attribute one, and the generation of a second message. In one minute of simulation time the model has generated two messages of a length selected at random from a normal distribution. This procedure, of

echoing transactions back to a source node, is an extremely convenient and comprehensible method of generating messages. A modeler can generate transactions with random inter-arrival times by selecting a desired probability distribution and assigning its sample value to activity one.

The first transaction arrives in queue node two at time zero plus the time assigned by activity two from the exponential distribution. The branch which this message traversed represents an activity which when executed has a time delay selected from this particular exponential distribution. The message resides in the queue until serviced by activity three which takes a constant twenty minutes to execute. Since this server is currently inactive, the message is immediately routed to conditional node four with a time delay of twenty minutes. Since queue node two has but one server, the second message may arrive before the server has released the message to node four. This second message must wait in the queue until server three is free. A third message, likewise, may arrive in the queue before the initial message has been released. As depicted inside and to the left of the queue symbol, there are zero messages initially in this queue and a queue capacity of five. If five trans-actions reside in the queue awaiting service, the sixth transaction is "balked" to the probabilistic node number three. The messages in the queue are serviced in a first-in, first-out procedure which is depicted by an 'F' in the center

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of the queue symbol. Queue nodes provide only a storage

function and do not cause explicit time delays. The time

for a transaction to traverse a network is specified on

activities or the branches of the network. Messages can

spend time waiting to be serviced from a queue; this waiting

time is actually the sum of the outgoing service times or

additional times associated with balking.

The message which arrives at node two, when the queue

is at capacity waiting service, will be balked directly

to the probabilistic node number three. The numbers on

the left of the symbol for node three, from top to bottom,

depict the initial number of transactions, and the subsequent

number of transactions required to release node three.

Fifty percent of the balked messages receive an additional

time delay selected from the normal probability distribution

with a parameter set maintained in parameter set three. The

remaining 50% of the balked messages receive a service time

determined by a user coded routine located in a user function

programming insert. Q-GERT provides the necessary flexi-

bility which allows the user to adapt the network, through

these coded inserts, to meet specific conditions that might

occur when a transaction passes through a node. The balked

messages are therefore probabilistically returned to queue

two where they wait servicing by activity three.

Activity three routes the messages to a conditional-

take first branch-node. In this particular situation, the

transactions fulfilling the first condition of attribute

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one is less than or equal to 50, depicted A1·LE·50 will be routed to the sink node number five. The transactions that do not meet this specification will be routed by activity seven to sink node number six.

In summary, in this simplistic network, messages of varying length are generated at one minute intervals. Two general categories of messages are routed to their respective sinks via a network that assigns service time penalties for messages that exceed the queue capacity. A run is terminated when either a specified number of messages arrive in the sinks or the simulation time exceeds a specified run time. The Q-GERT analysis program has been designed to collect a variety of statistics over a set of runs. Multiple runs are used to determine the variability of those statistics which the modeler considers important.

The Naval Postgraduate School's W. R. Church Computer Center currently has two Q-GERT programs in their library. The first is a 100-node, 100-arc capacity routine which models abbreviated networks. Its validity was confirmed by duplicating the exercises in Pritsker [3]. A second, larger capacity routine is available; however, its accuracy has not been confirmed. This 1000-node, 1000-arc program also was used with example problems; however, the output varied from Pritsker, and from the output of those examples which could also be accommodated by the smaller routine. Since demand for this expanded capacity model does not presently exist at the NPS, plus the fact that computer turnaround

time is longer, the 1000-node, 1000-arc program remains inaccurate and unused.

D.   THE COMSR DATA BASE

The Communications Support Requirements (COMSR) data base was investigated in an attempt to determine the traffic loading for the communications network of this thesis [7]. Army Regulation 105-9, dated 8 August 1977, states that all Army activities which are "concerned with the analysis, development, design, test and management of current and future communications equipment and systems" will use COMSR to "explicitly define" tactical communications requirements [8]. This regulation identifies areas where COMSR data should be used, including assisting users in analyzing, designing, and developing tactical communication concepts, evaluating the communications-electronics implications of future or proposed changes in doctrine, force development, equipment and weapons systems.

In 1973 the Computer Sciences Corporation completed a contract study which outlined the communications requirements for the concept of the Army in the Field (CONAF) D+90 force model in a specially designed 1980's scenario [9]. This study established the foundations for the COMSR report. The study included methods for developing, revising and maintaining the COMSR data base. A total of 587 typical units (TUN) were identified in the CONAF model. A typical unit was identified as a unit with a unique table of

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organization and equipment (TO&E). When two units with the
same TO&E were assigned at different levels of command,
each unit was classified as a separate TUN. Needlines were
developed between TUN units after an assessment of the
command/control, higher, lower, lateral, supported, supporting
and weapons system relationships. The traffic loading of
these needlines was determined by selecting the 24-hour
period within the given eight-day operational period of the
CONAF model that provides the best opportunity for the unit
to perform its assigned mission under suitably stressed
conditions. Based on established needlines and TUN unit
scenario activities, COMSR generated the probable amount of
voice, page, data, graphic, video and pouch traffic expected
between two TUN units. In 1974 the data base was validated
by the Combined Army Combat Developments Activity (CACDA)
through analysis efforts conducted by the U.S. Army Signal
School at Ft. Gordon, Ft. Hood, Ft. Bragg and Europe [10].

Periodically, the COMSR data base is updated or modified
during a CACDA sponsored COMSR review and analysis (R&A)
panel meeting, which includes representatives from each
TRADOC proponent school and combined arms and administration
centers. The R&A meeting considers the impact of changes
in operational concepts, organization structure, weapons
systems and the like, upon the COMSR data base. Changes to
the data base are made accordingly.

The brigade sized covering force identified in the Forward
Deployed Force Operations (European Setting) instruction

from the U.S. Army Command and General Staff College consists of two mechanized Infantry battalions, three tank battalions and one squadron of armored calvary. This packet of instruction considers the same European setting as the CONAF model and places the covering force within a specific area of operations. Using COMSR data to load the communications network of this force appeared valid because of the commonality between the CONAF model and the scenario setting of the covering force.

An extract of the COMSR data base is presented in Appendix C. Traffic in the COMSR is measured in total transmission time for the period by voice, page and courier. Table 1 summarizes the transmission measurements used in a COMSR report.

COMSR Transmission Measurements (24 hr. period)

MEANS	LENGTH
Voice	total transmission time measured in minutes
Page	total transmission length measured in pages
Pouch	total number of courier runs

Table 1

The lengths of the three means of communication are transferred to a common denominator for this study. Since messages are probabilistically routed to either courier,

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voice FM, or RATT, it appears logical to translate the COMSR output into a common denominator. Words per transmission is selected as the standard.

Minutes of FM voice transmission time was transformed into words per transmission by dividing the total transmission time by the message count. A voice transmission rate was then computed after a simple experiment. A text of typical tactical military communications was written. A military subject was instructed to read the message at a cadence appropriate for FM voice radio communications. This experiment was conducted three times on three different messages resulting in an average rate of transmission of 113 words per minute. This rate was then multiplied by the average minute length of the FM voice message to obtain the average length per transmission measured in words.

The unit of measure for the "page" means of communication is the 250-word page. The average length of a "page" transmitted message is computed by dividing the total pages for the 24 hour period by the number of messages in the same period and multiplying by 250.

The unit of measure for the traffic routed by courier is the "pouch". The "pouch" is synonymous with one dispatch of a courier. The number of "pouches" per 24 hour period equates to the same number of courier dispatches in the period. The average message length per message and message count per "pouch" is undefined in the COMSR report. For the purpose of this thesis a courier is dispatched when an

immediate message, or an accumulation of twenty routine and priority messages, are probabilistically routed to the courier routine. The average message length of a courier message is discussed in the courier section.

After further consideration, it was decided that the COMSR data base, in its current configuration, may not be appropriate for analysis at the level of resolution modeled in this thesis. The following deficiencies are identified with COMSR:

1. Considering the intensity of battle, and the demands for maneuverability of a mechanized unit, it appears likely that mechanized units will rely upon a courier more extensively than a unit under less rigorous demands for responsiveness and maneuverability. For the units in a COMSR mechanized TUN brigade, a courier was exercised only between a TUN tank battalion and the TUN brigade main.

2. The COMSR total message length includes channel checks, net maintenance calls and operator chatter; however, these individual transmissions are not included in the message frequency count. This aggregation causes greater average message lengths.

3. The COMSR consolidate all methods of voice communications into one category. One cannot determine the quantity and length of transmissions made via voice radio, wire line, or multi-channel.

4. Operations and Intelligence (O&I) traffic is included
    with administrative and logistics (A&L) traffic. One
    cannot separate the two to exercise parallel O&I and
    A&L nets which are utilized in a brigade.

These deficiencies have been identified in phone con-
versation with the United States Army Armor school and the
United States Army Infantry school [11]. Even though the
COMSR data base may be inadequate for realistic analysis
in this study, it was used to provide the necessary parameters
to load the first running of the Q-GERT model.

II. THE Q-GERT MODEL

A. INTRODUCTION

The communications network for a mechanized covering force was divided into the functional areas of FM voice, radio teletypewriter and motorized courier. Wire communication was assumed to be inconsistent with the extreme mobility of a mechanized covering force, and non-TOE communications equipment such as microwave or AM voice was assumed unavailable. The three functional areas were scrutinized for those variables which have the most pronounced effect upon communications. These variables were then incorporated into a communications topology, using Q-GERT notation, that individually modeled and linked each maneuver unit with the Brigade main using simplex voice, half-duplex RATT, and unscheduled courier. Unfortunately, even when using all of the procedures and routines available in Q-GERT, the brigade topology exceeded the 100-node and 100-activity capability of the Church Computer Center; therefore the brigade communications topology was again factored into simpler components. However, in this case communications were subdivided by operational units rather than by means. The communications generated from each of the maneuver battalions and the communications generated from the brigade main to the maneuver units were individually modeled. The outputs of these individual Q-GERT runs were

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then combined, sequenced, and routed in a final Q-GERT program to simulate the entire communications topology of the brigade in a continuous manner. This routine was designed in such a fashion that the interfaced output of the seven smaller programs would be equivalent to one output of the 1000-node/1000-arc program, if available. However, this routine could not be exercised in its entirety because of transaction limitations which will be discussed in a subsequent section.

The Q-GERT graphical representation of the communications from a maneuver unit to the brigade main is quite similar to the graphical representation of the communications from the brigade main to the maneuver units, although message length, precedence and message generation rates vary between the two subnetworks. The brigade main generates messages to the six maneuver units whereas each maneuver unit generates messages to five lateral units (possibly) and the brigade main. Since the topologies are so similar, only one complete Q-GERT graphical representation will be presented in this study. The entire topology is graphed in Appendix D. After a discussion of this topology, the interface routine will be graphically represented and addressed.
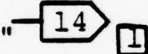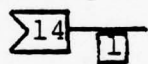
Table 2 summarizes the assignment of attributes within the Q-GERT topology of the battalion. The table includes the attribute number, the node where the attribute is

ATTRIBUTE ASSIGNMENTS

ATTRIBUTE NUMBER	NODE OF ASSIGNMENT	USE OF THE ATRRIBUTE
1	1,2,3	precedence (5-Routine, 6-Priority, 7-Immediate)
2	11,12,43	probabilistic and deterministic selection of message lengths
3	4	probabilistic selection of message addressee
4	42,43	probabilistic selection of unit movement
5	13,15,18	courier message counter
6	8,10,15,24 41,42,43, 52,56,58, 59,61,62, 67,4	various administrative functions including write statement access, sink node identification, etc.
7	1,2,3	message time of entry into network
8	4	message origin by unit
9	8,50,54,57	beginning time of radio transmission

Table 2

assigned, and the use of the attribute. There are a
total of nine attribute assignments possible for each
message traversing the network.

The detailed discussion of this communications topology
is divided into four sections. Section B describes the
generation of three precedence-classes of messages, and the
preparation routines for the message prior to traversing the
network. Section C describes the courier routine. Section
D describes the Operations/Intelligence (O&I) and Administrative/
Logistics (A&L) FM voice radio nets, and Section E discusses
the radio teletypewriter network. Two non Q-GERT symbols
will be used to link sections together. The symbol
" $-\boxed{14}\boxed{1}$ " denotes that messages traversing "activity 14
into exit 1" will be connected with the symbol " $\boxed{14}\boxed{1}$ "
which is the "receive 1 into activity 14" in a subsequent
section. Exit and receive paired numbers will be used once
in an ascending order.

B. MESSAGE GENERATION

Figure 2 diagrams the five regular nodes, one queue
node, and eleven activities which represent the message
generation function and initial message preparation for the
topology.

Three precedence categories of messages are generated
at regular nodes 1, 2, 3. Node 1 and the associated "loop",
activity 1, cause the generation of routine messages into the
network. Activity 1 performs the "echo" function previously

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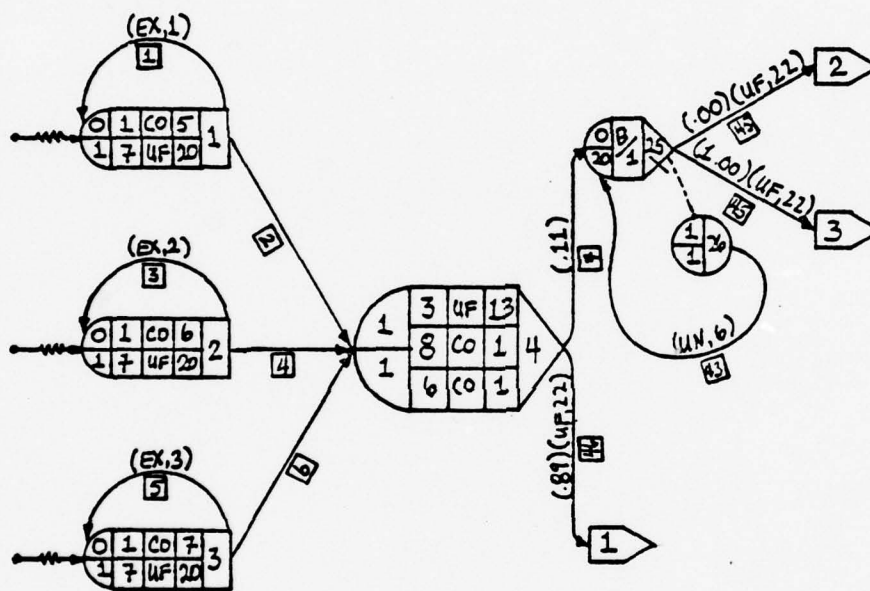
FIGURE 2

described. Routine messages are generated with an exponentially distributed inter-arrival time as described in parameter set 1. The exponentially distributed inter-arrival time selected is generally accepted for message inter-arrivals in communications networks. The information necessary to describe the truncated exponential distribution in parameter set 1 includes: the mean value, the minimum value, and the maximum value.[*] In Q-GERT this information is used to randomly select a value which is returned to activity 1 as the inter-arrival time. The average message generation rate for routine messages, as derived from the COMSR data base, is one per 6.13 minutes.

The notation inside node 1 signifies that attribute 1 is assigned a constant value of 5 (to represent a routine message). The notation "7 UF 20" signifies that attribute 7 is assigned a value using the 20th user function. This is done by having the Q-GERT program call the "Function UF(IFN)" routine with "IFN=20". User function 20 assigns to attribute 7 the time the message was actually generated.

_____

[*]The exponential and the normal distributions are slightly modified in the Q-GERT Routine. These distributions are "truncated", and any sample drawn from these distributions which is outside the specified minimum and maximum values is set at the minimum or maximum value. The reader is referenced to page 208 of Pritsker for elaboration.

Figure 3 displays UF(20) which uses the Q-GERT function
TNOW to assign the current simulation time to attribute 7.

                    User Function 20

         20 UF=TNOW
            RETURN

                       Figure 3

Thus, prior to departing node 1, each message has two of
eight attributes assigned.

The procedure for generating priority and immediate
messages at regular nodes 2 and 3, respectively, is virtually
identical to that described for node 1. The main differ-
ence is that the inter-arrival time for priority messages is
defined by parameter set 2, and immediate messages have an
inter-arrival time described by parameter set 3. Referring
to Appendix C, priority messages have an expected arrival
interval of 25.2 minutes. A minor difference is that attri-
bute 1 receives a constant value of 6 for priority messages
and 7 for immediate messages. (The COMSR data base does not
predict any immediate messages from the brigade, therefore,
the topology available to generate this class of messages
will not be used for the brigade subnetwork. The immediate
message generating routine will be used, however, for
communications from the battalions.)

All three precedence-class messages are routed to regular node 4. When arriving at regular node 4, all messages have values for attributes 1 and 7. At node 4 attributes 3, 6 and 8 are assigned.

Attribute 3, used to identify the addressee, is assigned by the 13th user function. This user function selects a value from a random number generator, conducts a conditional check based on the data included in Appendix C and returns an integer to the attribute. Figure 4 displays UF(13).

User Function 13

```
13 RN=DRAND(1)
   IF(RN.GT..00.AND.RN.LE..19) UF=1 TANK BATTALION 1
   IF(RN.GT..19.AND.RN.LE..38) UF=2 TANK BATTALION 2
   IF(RN.GT..38.AND.RN.LE..57) UF=3 TANK BATTALION 3
   IF(RN.GT..57.AND.RN.LE..77) UF=4 MECHANIZED BATTALION 1
   IF(RN.GT..77.AND.RN.LE..97) UF=5 MECHANIZED BATTALION 2
   IF(RN.GT..97.AND.RN.LE.1.0) UF=6 ARMORED CAVALRY SQUADRON
   RETURN
```


Figure 4

The Q-GERT function DRAND(1) generates pseudorandom numbers between 0 and 1, where the (1) identifies the random number stream to be employed in generating the random number. Ten streams are available in the Q-GERT analysis program, and a random number seed initialization card, SEE, is used to specify a starting value for the random number stream used. In this study only the first stream is used and the random number stream is not re-initialized for multiple simulation runs. COMSR indicated approximately

19% of all messages generated by the brigade are intended for a tank battalion, 20% for a mechanized battalion and 3% for the squadron. The "IF" statements in UF(13) are bracketed accordingly.

Attributes 8 and 6 denote, respectively, the echelon at which a message was generated and the means used to communicate the message in the network. In Table 3, attribute 8 receives a value of 1 to indicate that the brigade main originated the message. In subsequent simulation runs other values will be assigned to attribute 8. Table 3 lists the originator assignment for attribute 8.

Originator Assignment for Attribute 8

Value	Originator
1	BDE Main
2	TK BN 1
3	TK BN 2
4	TK BN 3
5	MECH BN 1
6	MECH BN 2
7	AR CAV SQD

Table 3

For all messages, attribute six is initially assigned a constant value of one at node four to denote that the message will be routed via courier to the addressee indicated

in attribute three. For those messages later probabilis-
tically routed by radio or RATT, attribute six is reset
to another value in a subsequent node. Table 4 lists the
values for attribute six and the corresponding means of
communications. Included in this table are value assignments
for those messages which are lost to the system because of
jamming. (Jamming routines will be discussed later.)

Value Assignment for Attribute Six

Value	Means/Reason for Loss
1	Courier
2	O/I FM Voice
3	RATT
4	FM Voice jamming (unit stationary)
5	FM Voice jamming (unit moving)
6	A/L FM Voice

Table 4

The reassignment of values for attribute six will be
elaborated on in the next sections.

In summary then, five of the eight possible attribute
assignments have been completed after a message is released
by regular node four. They are listed in Table 5.

Attribute Assignment Summary

Attribute #	Meaning
1	Precedence
3	Addressee
6	Communications means
7	Time of origin
8	Unit of origin

Table 5

Upon exiting node four, 11% of the messages are routed via activity seven to queue node 25, and 89% of the messages are routed via activity 46 to the FM voice section via the "exit 1" routine. These percentages were derived from the COMSR data base included in Appendix C. Activity 46 calls user function 22 to determine the message handling time, which could be described as the handling delay from the author of the messages to the FM voice radio operator. User function 22 is included in Figure 5, where Al stands for the value of attribute one.

User Function 22

```
  22 IF(A1.EQ.5) GO TO 1000
     RN=UN(10)
     UF=RN
     RETURN
1000 RN=UN(11)
     UF=RN
     RETURN
```

Figure 5

Two message handling rates are utilized in this function. Routine precedence messages (A1.EQ.5) have a message handling time randomly selected from the uniform distribution described by parameter set 11. Parameter set 11 has a minimum value of 10 and a maximum value of 20 minutes handling time. These values were selected based on the author's experience as a brigade signal officer. Other than routine messages routed to activity 46 have a message handling time randomly selected from the uniform distribution described in parameter set 10. Parameter set 10 has a minimum and maximum value of 5. and 10. minutes respectively to represent "faster" message handling times for higher precedence messages. Activity 46 terminates in the FM voice routine which will be discussed in an upcoming section.

The 11% of the messages routed from regular node four to queue node 25 represent record traffic routed to a message center clerk, where it is accounted for and then routed to the appropriate means available. Queue 25 has a capacity of 20 messages. The messages that have the largest value of attribute one, depicted by "$3/1$" in the center of the queue node, receive priority in the servicing from the queue node; that is, higher precedence messages are serviced first by the message center clerk. If 20 messages accumulate in the queue, subsequent messages balk to regular node 26. The message will be returned to the queue with a time penalty assigned from the uniform distribution with a

minimum and maximum value of 5 and 10 minutes respectively. Exceeding the queue capacity, routing a message to regular node 26, and returning a message to queue node 25 with a time penalty simulates the inefficiency of a message center clerk as more and more messages accumulate awaiting processing. The time penalty reflects the additional time necessary to process messages when confusion exists. At the brigade level, experience of the author shows that a message center clerk will service and route messages effectively when less than approximately 20 messages await attention. More than 20 messages will cause inefficiency and increase message handling time.

Messages are probabilistically routed out of queue 25 to the courier and RATT routines. Since the COMSR report does not emphasize the use of courier, the server servicing the activity to the courier routine has a .00 percent probability of usage. In subsequent Q-GERT routines this branch will be used, when appropriate, to exercise the courier network. One hundred percent of the messages exiting queue 25 will be serviced into the RATT network via the server 45, "exit 3" routine.

C. COURIER ROUTINE

Figure 6 includes one source node, one sink node, four regular nodes, two queue nodes, one match node and seven activities which represent the courier network. The courier is dispatched when an immediate message is received

39

COURIER ROUTINE

FIGURE 6

40
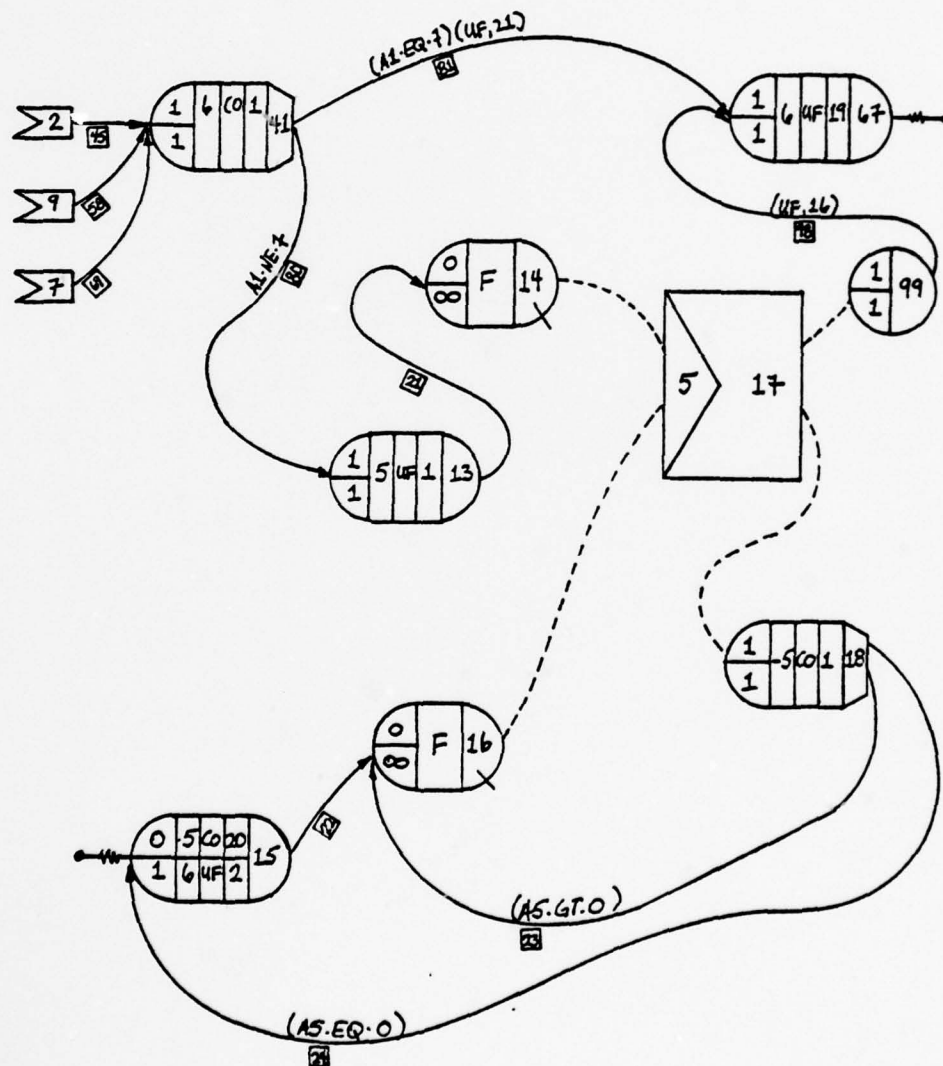
or when twenty non-immediate messages are accumulated. This section describes this mechanism in detail.

Section B discussed the probabilistic routing of messages into server number 45 which routes messages into the courier network at the "receive 2" symbol. Messages are also routed to the courier when certain situations exist in other portions of the topology. When the RATT network is successfully jammed a certain percentage of messages are given to the courier for delivery. These messages are "delivered" to regular node 41 by activity 58 and the "receive-9" symbol. When the FM voice networks are successfully jammed a certain percentage of messages are routed to the courier via activity 69 and the "receive 7" symbol. Node 41 resets attribute six to a value of one to denote that the message was delivered via courier. Node 41 also conditionally routes messages to subsequent nodes based upon the value of attribute one (precedence). If the message has an immediate precedence a courier will be dispatched immediately. This is modeled by activity 81. The time of delivery of the message is determined by user function 21 which randomly samples the uniform distribution described by parameter set nine. The minimum value of 20 minutes and the maximum value of 80 minutes of this parameter set were calculated based upon the distances between the closest and farthest unit from the brigade main of the Ft. Leavenworth scenario and an assumed average courier speed of 25 mph [12].

Activity 80 routes routine or priority messages from
regular node 41 to regular node 13. Attribute 5, a counter
which is used to cause messages to be "held" in a queue
until twenty accumulate, receives a value computed by user
function 1 at regular node 13. User function 1 is depicted
in Figure 7.

User Function 1

```
1 NPS=NPS+1
  UF=NPS
  RETURN
```

Figure 7

The variable NPS was initialized to zero at the beginning
of the simulation by including one unconnected source node
that called this user function. Figure 8 shows a typical
unconnected source node which is released once at the
beginning of each simulation run.

Initializing Node
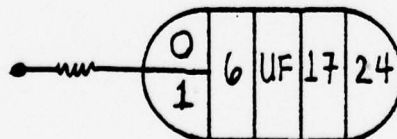
Figure 8

Attribute six, in this case, performs no function other
than allowing the "call" to user function 17 (Figure 9)

which performs the initialization function. A number of
variables are initialized by this one call to user function
17.

<div align="center">

User Function 17

</div>

```
17 TMOVE=0
   TSTOP=3000
   DY=1
   DUMMY=1
   TIME=0
   SAMP1=0
   SAMP2=0
   NPS=0
   RETURN
```


<div align="center">

Figure 9

</div>

Although one transaction is generated by this unconnected
source node, it does not enter the network or otherwise
interfere with the topology.

Activity 21 routes the individual messages from regular
node 13 to queue node 14, where the messages reside until
the simulated dispatch of the courier. Match node 17
causes queue node 14 to retain messages until a certain
condition is met in queue node 16. Match nodes are used to
force transactions to wait until another transaction in
another queue node achieves a particular status. When the
value of attribute 5 is the same for a message in queue 14
and for a transaction in queue 16, a match is said to exist

<div align="center">

43

</div>

and match node 17 releases. One of the twenty messages is
allowed to traverse the match node to sink node 67 via node
99 and a transaction is allowed to traverse to regular node
18. Activity 98 assigns the courier delivery time by
calling user function 16 (Figure 10). User function 16
returns a constant delivery time for each group of twenty
messages.

User Function 16

```
16 IF(A5.EQ.1) GO TO 300
   UF=DT
   RETURN
300 DT=UN(9)
   UF=DT
   RETURN
```

Figure 10

At the beginning of the simulation, a transaction departing
the source node 15 is assigned a value of 20 for attribute
5, the match attribute. Additionally, attribute six calls
user function two which initializes NPS to zero. Once
again attribute six is only used to gain access into the
user function routine.

Node 15 performs a similar function to that of the
unconnected source node 24 previously addressed. Node 15,
however, is allowed to be released more than once. NPS
is, therefore, initialized at a value of zero before messages
arrive into the network. One transaction with attribute five

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equaling twenty resides in queue node 16 waiting for the arrival of the 20th message into queue node 14. When this message arrives, attribute five is matched in both queues and the match node releases as described. Attribute five for the transaction is decremented by one, depicted by "-5 CO 1" inside regular node 18. Attribute five now equals 19. The transaction is immediately routed back to queue node 16 by activity 23. When the transaction returns to queue node 16 another match occurs with the 19th message in queue 14 and the match on attribute five once again exists. This cycle continues with no time delay until the first arriving message is queue 14 is allowed to pass to sink 67. When this occurs, node 18 simultaneously zeros attribute five of the transaction, whereupon it meets the condition of activity 24 and is routed to source node 15. Source node 15 is immediately released, attribute six is again set to 20, NPS is set to zero and the transaction is passed to queue node 16. Since NPS is once again zero, and since the execution of the 20 matches occurred instantaneously, the next message routed through regular node 13 receives a value of one for attribute five. A match does not exist because the value of attribute five of the transaction residing in queue node 16 is 20. As messages pass through regular node 13, attribute five eventually reaches 20, whereupon a match exists, and queue node 14 releases all 20 messages to sink 67. User function 19 (Figure 11) is called at sink node 67 to write or punch out the attribute values of the message,

45

```
  19 UF=1
     THRPUT=TNOW-A7
     WRITE(6,555) TNOW,A7,A9,A1,A2,A3,A4,A5,A6,A8
 555 FORMAT(1X,3(F5.0,1X),1X,F2.0,1X,F4.0,1X,2(F2.0,1X),F3.0,1X,2(F3.0,
    1  1X))
     RETURN
```

Figure 11

plus TNOW, the time the message entered the sink. These

variables will be used to route messages in the subsequent

Q-GERT interfacing routine.

D. OPERATIONS & INTELLIGENCE (O&I), AND ADMINISTRATIVE
    & LOGISTICS (A&L), FM VOICE ROUTINES

Figure 12 includes seven regular nodes, one queue node,

two sink nodes and twelve activities which model the O&I

FM voice portion of the topology.

Section A discussed the probabilistic routing of

messages to activity 46 and the "exit 1" symbol. These

messages are routed into regular node 11 via activity 46

and the "receive 1" symbol. The value for attribute two

is determined from the truncated normal distribution des-

cribed by parameter set four. Attribute two represents the

FM voice message length measured in words as derived from

the COMSR data base. Parameter set 4 lists values of 391,

323, 540 and 29.04 as the expected mean, minimum, maximum

and standard deviation. Messages are then routed to the

conditional branching node 42 where attributes four and six
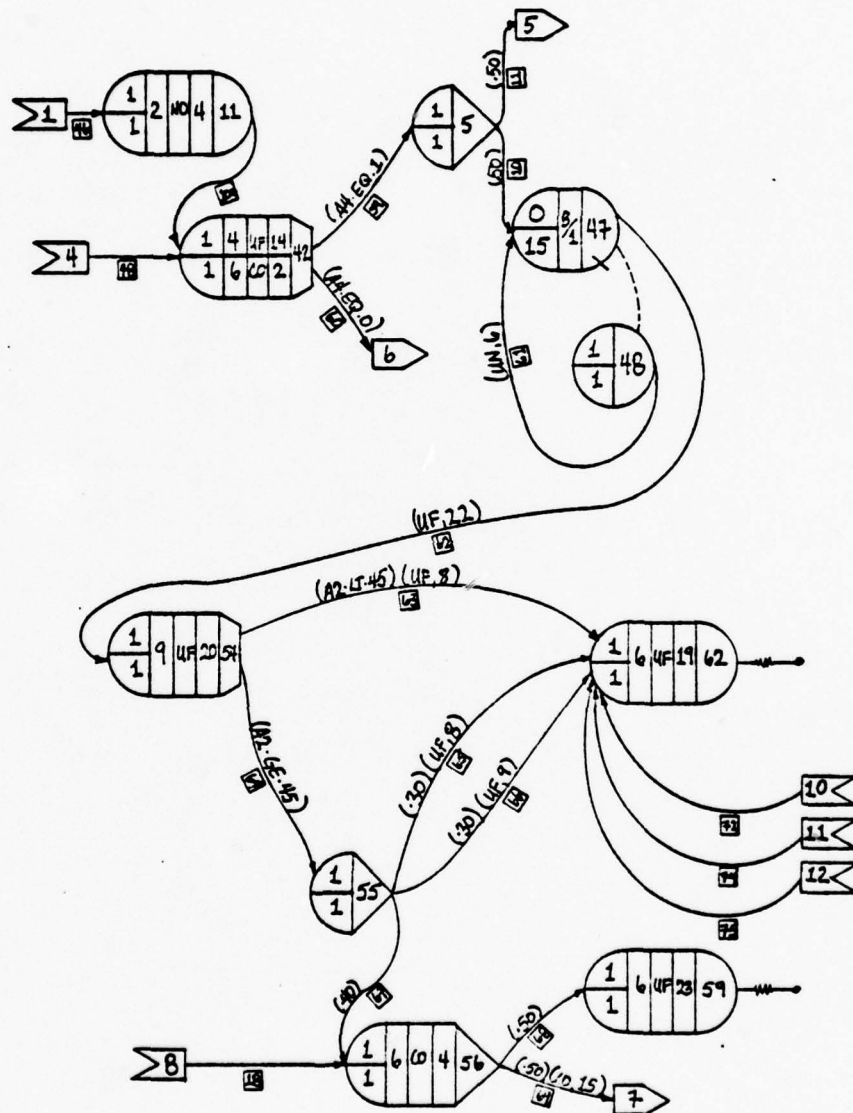
FIGURE 12

are assigned values. (Note activity 48 also directs messages
into node 42. Activity 48 is "connected" to the RATT
routine and is utilized when certain conditions, which
will be addressed in a subsequent section, exist in that
routine). Attribute four is used to route messages in a
different manner depending on whether the unit is moving
or stationary. User function 14 (Figure 13) randomly
selects the time a unit will begin to move and the duration
of the move.

User Function 14

```
 14 IF(DUMMY.EQ.0.) GO TO 88
    IF(DY.EQ.0) GO TO 87
    SAMP1=UN(7)
    DY=0
    TMOVE=SAMP1+TNOW
 87 IF(TNOW.LE.TMOVE) GO TO 99
    SAMP2=UN(8)
    TSTOP=TMOVE+SAMP2
 88 IF(TNOW.GE.TSTOP) GO TO 99
    DUMMY=0
    UF=0
    WRITE(6,260) TNOW,TMOVE,TSTOP,SAMP1,SAMP2
260 FORMAT(1X,5(F5.0,1X),1X,' MOVING ')
    RETURN
 99 IF(TNOW.GE.TSTOP) DY=1
    DUMMY=1
    UF=1
    WRITE(6,160) TNOW,TMOVE,TSTOP,SAMP1,SAMP2
160 FORMAT(1X,5(F5.0,1X),1X,' STATIONARY ')
    TSTOP=3000.
    RETURN
```

Figure 13

Recall that at the beginning of the simulation one release
of isolated regular node 24 caused the following variable

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assignments:

$$TMOVE = 0$$
$$TSTOP = 3000$$
$$DY = 1$$
$$DUMMY = 1$$
$$SAMP1 = 0$$
$$SAMP2 = 0$$

Considering these initialized values, a brief explanation of user function 14 will be given.

SAMP1 receives a value from the uniform distribution described in parameter set seven. SAMP1 is fixed until the unit completes its move, whereupon another SAMP1 value is selected to set the time of the next move. SAMP1, when added to TNOW, the simulation time when user function 14 is first called, becomes the simulation time when the unit starts its move, or TMOVE. Parameter set seven has minimum and maximum values, based upon expected command post (CP) displacement rates stated in FM 24-1, Combat Communications, of 300 and 420 minutes, respectively [13]. This manual predicts a brigade CP will displace three to five times per day, or an average of once every 360 minutes. One hour was subtracted and added to this average to establish the lower and upper bound for the uniform distribution.

As long as the current simulation time, TNOW, is less than TMOVE the unit remains stationary, user function 14 returns a value of one to attribute four, and messages are routed to regular node five. When the first message arrives into node 42 and user function 14 is called at a

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time greater than TMOVE, SAMP2 is obtained. SAMP2 comes from
the uniform distribution with values of 60 and 120 minutes
for the minimum and maximum values. (These bounds were
selected based upon experience of the author and the Ft.
Leavenworth scenario.) The time that the unit stops its
move is TSTOP or TMOVE plus SAMP2. Then, as long as TNOW
is less than TSTOP, the unit is still moving and user
function 14 returns a value of zero to attribute four. The
message is routed via activity 60 to "exit-6" where message
handling is different than when the unit is stationary.
When the unit is moving all FM voice radio messages, both
A&L and O&I, are routed via activity 60 to a subnetwork
which will be described at the end of this section. During
the confusion of a displacement more emphasis may be placed
upon the O&I network; given this, it is likely that this
network will be functioning whereas the A&L net may not be
operating.

When the unit is stationary, user function 14 returns
a value of one for attribute four and all messages are
routed to the probabilistic-branching regular node five.
Fifty percent of the messages are subsequently routed via
activity 11 to "exit-5" where the messages enter the A&L
network and fifty percent of the messages to the messages
to the O&I. These percentages were later varied to observe
the sensitivity of the network. The results of changing the
percentage routed via the two nets will be discussed in
Chapter 4. Activity ten routes messages to queue node 47

where radio operators rank-order arriving messages according to precedence. The radio operator has a queue message capacity of 15. Messages exceeding his queue will be balked and returned with a penalty assigned from the uniform distribution having parameters described in parameter set 6 previously addressed. User function 22 returns a message handling time for the radio operator. Regular node 54 routes those messages that are shorter than 45 words directly to sink node 62. User function 20 sets attribute nine equal to the time a radio operator first starts to transmit the message. The activities linked to node 62 originate from the FM voice network used when the unit is moving. The Battlefield Survival Threat Handbook, published by the Training and Doctrine Command states that after 25 seconds of transmission time, RDF stations have had sufficient time to acquire bearings and approximate the radio's location for jamming, monitoring or destruction [14]. The average rate of transmission for voice messages is 113 wpm which was previously derived. At this transmission rate, a message of approximately 45 words or less probably will be transmitted without being exposed to jamming. Activity 63 models this situation with conditional branching and calls to user function eight (Figure 14) to determine the time of transmission for the message.

User Function 8

```
8  UF=(A2/113)+10
   RETURN
```

Figure 14

For those messages longer than 45 words, or 25 seconds of transmission time, one of four events may occur: (1) the message will be successfully transmitted with a considerable time delay because of jamming, (2) the message will be allowed to pass without interference and intelligence will be gained through monitoring, (3) the message will be successfully jammed and the FM voice operator will give up and the message will be lost, (4) the message will be successfully jammed and the operator will route the message to another means. A jammed but successfully transmitted message is modeled by activity 66. User function nine (Figure 15) determines the transmission time given the necessity for a second transmission.

User Function 9

```
9 UF=(A2/113)*2+10
  RETURN
```

Figure 15

The message which is just monitored is modeled by activity 65 which has the same message transmission time as activity

63.   Those messages which are successfully jammed are routed
to regular node 56 by activity 67. Attribute six is set
to four denoting that the message was successfully jammed.
It is assumed that the operator will either give up or think
a message has been successfully transmitted 50% of the time.
In this case messages are routed to sink node 59 where user
function 23 is used to print out the message's attribute
values. The remaining 50% of the messages are delivered to
the courier routine via activity 69 and the "exit-7" symbol.
Each message is delivered with a constant 15 minute time
delay. The "receive-8" into activity 18 transfers those
messages that were jammed in the A&L net.

Returning to the regular node 42, when attribute four
equals zero, or the unit is moving, all FM voice messages
are routed into one network. This network consists of two
queues, two sinks, three regular nodes and nine activities
depicted in Figure 16. Messages are routed into and rank
ordered according to precedence in queue node 49. Queue node
49 and 53 perform a blocking function which simulates the
reduction of efficiency in a radio operator when exposed to
the distractions of a move. A message is allowed to enter
into queue number 49; however, it remains in this queue
until queue 53 is empty. Queue node 53 cannot release until
server 71 is free. Attribute nine is set to the time a
radio operator starts transmitting a message and attribute
six receives a value of two, denoting that the message was
transmitted via this net at regular node 57. Messages

53
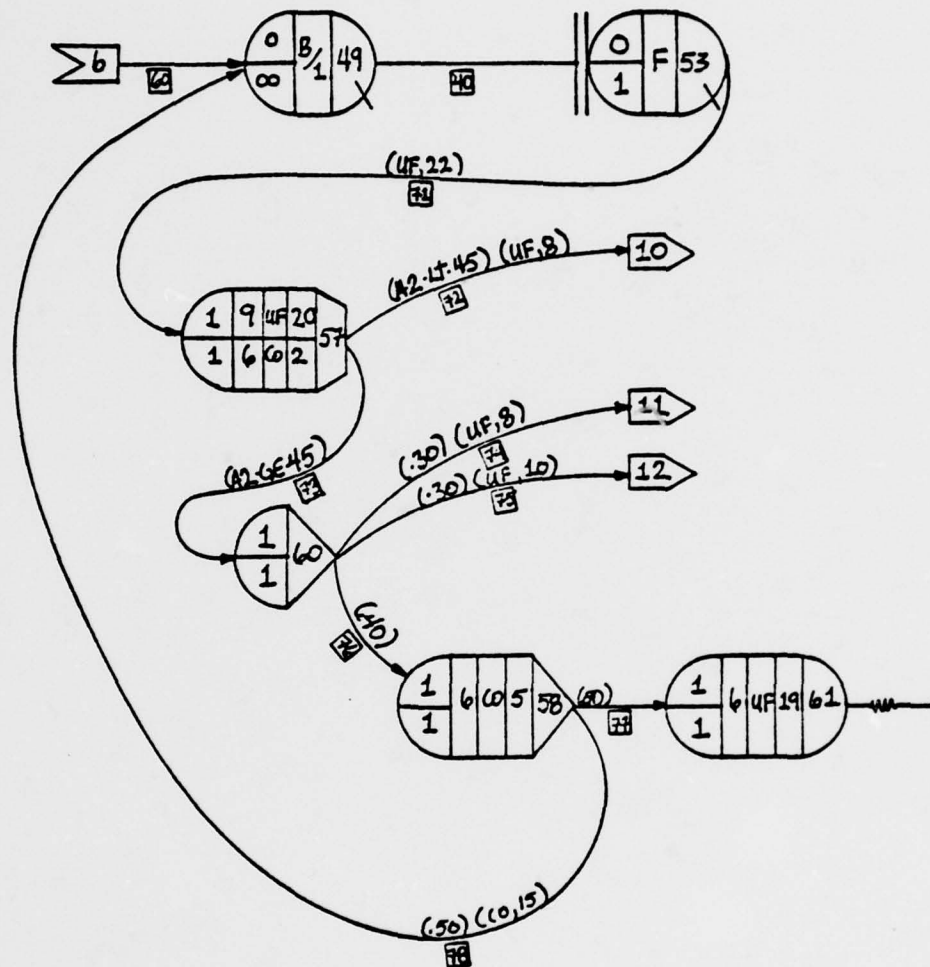
FIGURE 16

shorter than 45 words are routed via activity 72 to the "exit-10" symbol and subsequently into sink node 62. The time of transmission for these messages is computed the same way as "shorter" unjammed messages discussed earlier in this section. Those messages exceeding 45 words in length are subject to jamming and are routed accordingly.

Figure 17 diagrams three regular nodes, one queue node, one sink node and eight activities which models the A&L FM voice portion of the topology. Messages are probabilistically routed into the A&L network from node five via activity 11 and the "receive-5" symbol. Messages are processed through this network similarly to the O&I network with one exception. A certain percentage of messages that are over 45 words are not successfully transmitted to sink node 10. These messages are routed via "exit-8" to regular node 56 of the O&I net for disposition. They are subsequently lost to the system or are routed to the courier.

E. RADIO TELETYPEWRITER TOPOLOGY

Figure 18 diagrams five regular nodes, one queue, one sink and 11 activities which represents the radio teletypewriter network.

Messages are probabilistically routed to regular node 43 from queue node 25 via activity 45 and the "receive-3" symbol. At node 43, attribute two is assigned the length of the message from the uniform distribution with a

A&L FM VOICE TOPOLOGY (STATIONARY)

FIGURE 17

56
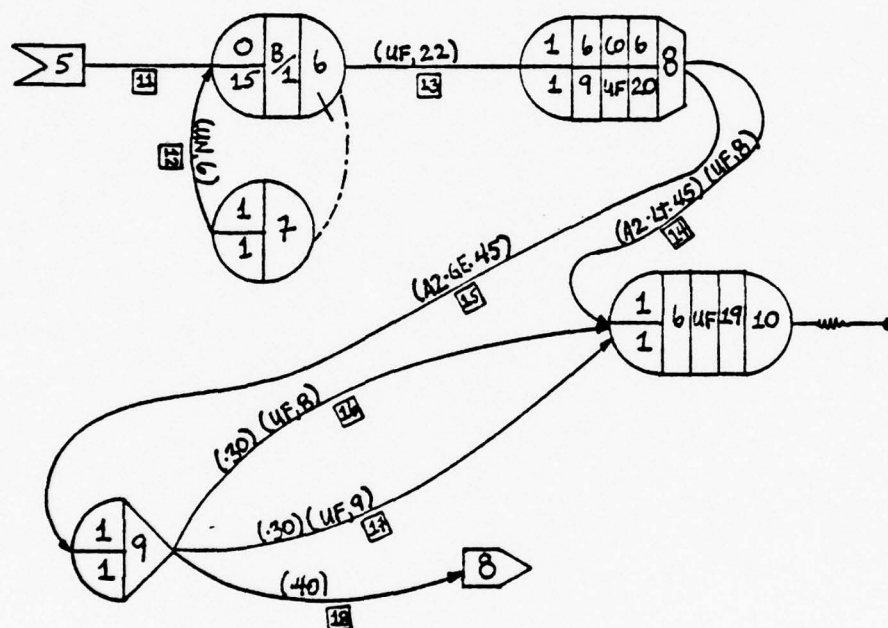
RADIO TELETYPEWRITER NETWORK
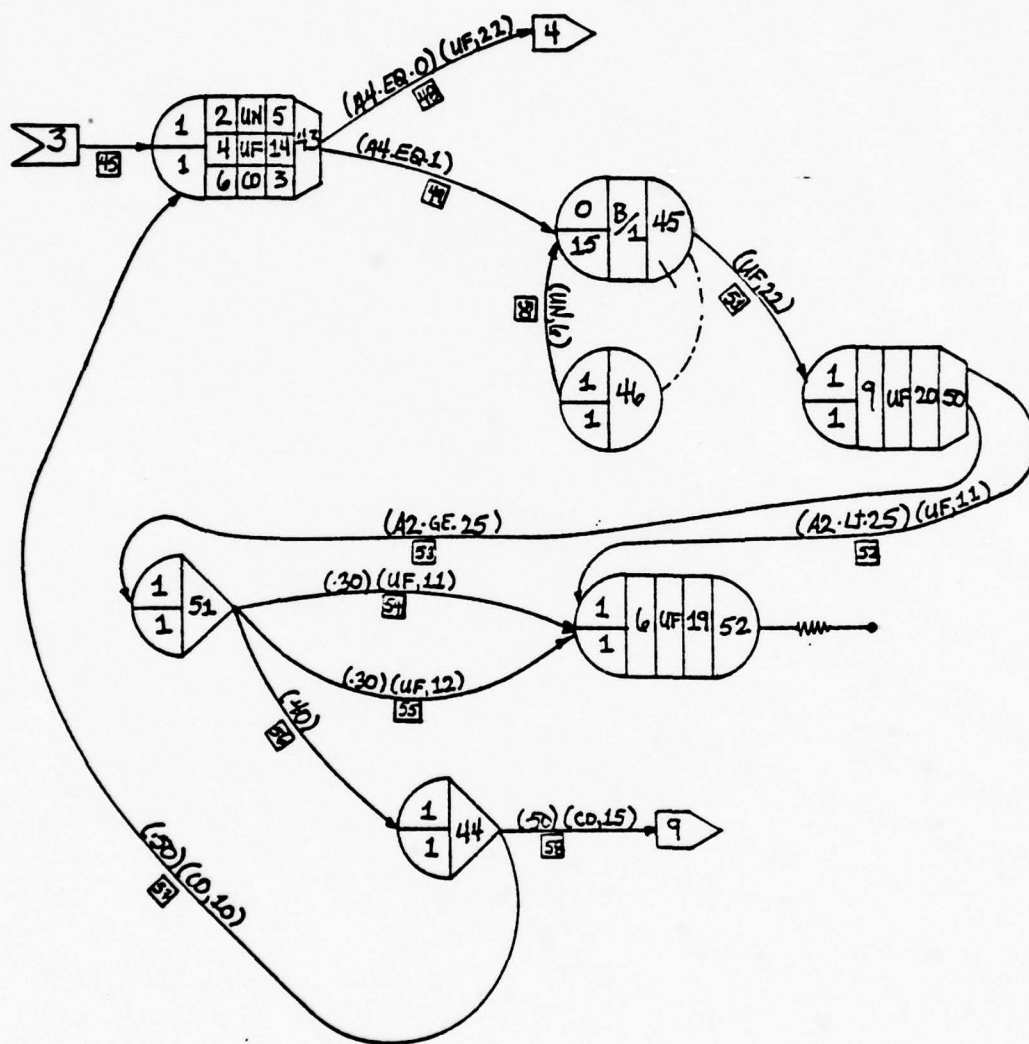
FIGURE 18

parameter set five. Parameter set five has a minimum and maximum value of 225 and 275 words respectively. The COMSR data base predicts the average page message will have 250 words. The minimum and maximum values are computed by taking 10% of 250 and subtracting and adding it to the average. As before, user function 14 is used to determine the time and duration of the move. A zero is assigned to attribute four if the unit is moving; a one is assigned if stationary. Attribute six, denoting that the message was sent via RATT, receives a constant value of three. If the unit is moving, activity 48 routes the message to the FM voice network via the "exit-14" symbol. This simulates the fact that when a unit is moving messages are probably sent via FM voice rather than RATT. When stationary, messages are routed through queue node 25 to regular node 50 where attribute nine is assigned.

A message of 25 words or less will probably be transmitted without jamming interruption as the transmission time is less than 25 seconds. Messages greater than 25 words will probably be subject to jamming. With jamming, one-half will be redirected back into the RATT queue and the other one-half routed to the courier for disposition.

User functions 11 and 12 are included in Figure 19. User function 11 assigns a transmission time without jamming signal and user function 12 assigns a transmission time given the operator must transmit the message three times to get it through.

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User Functions 11 And 12

```
11  UF=((A2/60)+(A2/40)+10)
    RETURN
12  UF=((A2/60)*3+(A2/40)+10)
    RETURN
```

Figure 19

User functions 11 and 12 are based upon the assumption that a moderately proficient typist can type 40 wpm and the teletypewriter equipment of the RATT is set at 60 wpm.

In summary the brigade model generates and probabilistically routes by different means three classes of messages to sink nodes. Messages are delayed, lost, or resorted according to certain conditions specified by the modeler. This study considers jamming as a function of message length, confusion resulting from a unit movement and/or an accumulation of unserviced messages, and probabilistic routing.

The simplicity of Q-GERT facilitates the investigation of limiting conditions. A certain situation is analyzed by a modeler by modifying and reinserting a few input cards for a subsequent simulation run. (For example, to change the percentage of messages routed to voice means an analyst modifies two data cards.) The capability of the model to easily and quickly adapt to relatively significant changes illustrates the tremendous flexibility of Q-GERT.

CHAPTER III.   THE Q-GERT INTERFACE ROUTINE

A.   INTRODUCTION

The 100 node, 100 arc Q-GERT program is limited in the
number of concurrent transactions traversing the network.
In Q-GERT, concurrent transactions are found in queues,
activities or servers and are a function of the number of
attributes assigned per transaction or message. The number
of concurrent transactions must be less than 1600 divided
by the number of attributes per transaction +1 [15]. In
this study each message has 11 attributes; therefore,
approximately 130 concurrent transactions are allowed. This
situation prevents the modeling of all the functions of the
interface routine simultaneously. Accordingly, only the
courier and O&I FM network are modeled in this chapter.

The Q-GERT interface routine performs a synchronization
and message routing function. One hundred and eighty five
messages generated from the six Q-GERT runs are used to load
this final run. The messages are first sorted according to
the means of communication, then routed to address queues.
Those messages sent by radio are assigned a waiting time
which represents the time a radio operator waits until the
net is clear of traffic and a message is transmitted. This
chapter is divided into two sections: Section B discusses
the message input routine and Section C discusses the network.
The entire network is graphed in Appendix D.

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B. MESSAGE INPUT

A single unconnected regular node is released at time = 0 to initialize the variables used in the interface routine. Regular node 99 and the associated user function 4 are shown in Figure 20.

Node 99 And User Function 4

```
4  ALAST=0.0
   NN=0
   NT=0
   RETURN
```
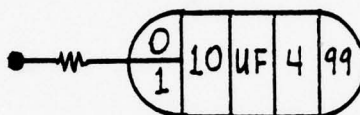

Figure 20

Messages enter the interface routine at node one (Figure 21) by a read function.

Nodes 1 And 38
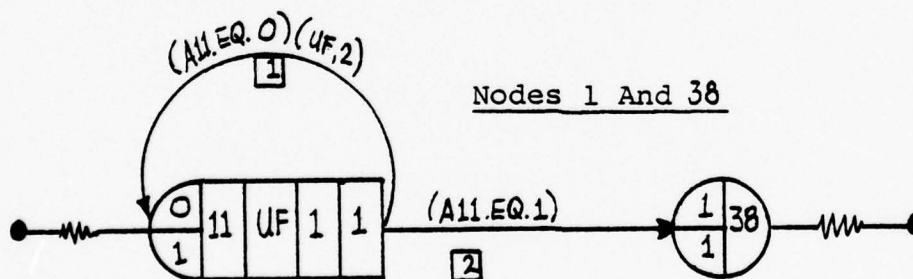
Figure 21

User function one (Figure 22) "reads" a message and attribute 11 is used to conditionally return an "echo".

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User Function 1

```
  1 READ(5,100) TTNOW,A7,A9,A1,A2,A3,A4,A5,A6,A8
100 FORMAT(2X,F4.0,2(1X,F5.0),1X,F3.0,1X,F4.0,2(1X,F2.0),
   12X,3(F2.0,1X))
    NN=NN+1
    IF(A7.LT.0.0) UF=1
    RETURN
```

Figure 22

If A7 is negative (on the last data card), attribute 11 is set to one, the argument of activity one fails and the message input routine is terminated.

User function two (Figure 22) uses the PTIN subroutine to insert messages into the network at node two. Each message is inserted with a 0.0 time delay, a mark time of TNOW and an attribute vector previously defined with 11 attributes.

User Function 2

```
  2 ATT(1)=A1
    ATT(2)=A2
    ATT(3)=A3
    ATT(4)=A4
    ATT(5)=A5
    ATT(6)=A6
    ATT(7)=A7
    ATT(8)=A8
    ATT(9)=A9
    ATT(10)=TTNOW
    ATT(11)=0.0
    CALL PTIN(2,0.0,TNOW,ATT)
    UF=0.05
    RETURN
```

Figure 23

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An insignificant activity time of .05 minutes is assigned
to user function eight to "space" the reading process out
to prevent the simultaneous arrival of all the messages
into node two.

Initially in this study, user function two was set to
zero and the READ function was completed in 0.0 minutes
simulation time. As a result, an excess of 130 transactions
simultaneously arrived in the network, causing a terminating
error.

C. INTERFACE NETWORK

This section is divided into three parts. Part one
addresses the sorting of messages by means, Part two
addresses the courier subnetwork, and Part three addresses
one radio subnetwork. The topology, for the FM and RATT
networks are similar, therefore, only the O&I network will
be presented in this chapter.

1. Message Transmission Interface

One regular node and four activities (Figure 24)
sort messages according to the means of message transmission.
Note that there are no "incoming" activities into node two
because of the PTIN subroutine.

The "exit-2" symbol is linked to the courier sub-
network and the "exit-3" symbol is linked to the O&I sub-
network. Sink nodes 12 and 13 represent the A&L and RATT
subnetworks respectively.

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MESSAGE SORTING NODE
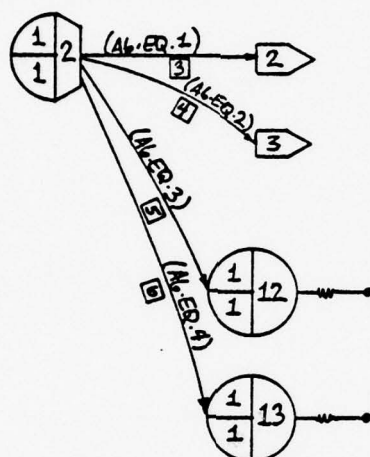
FIGURE 24
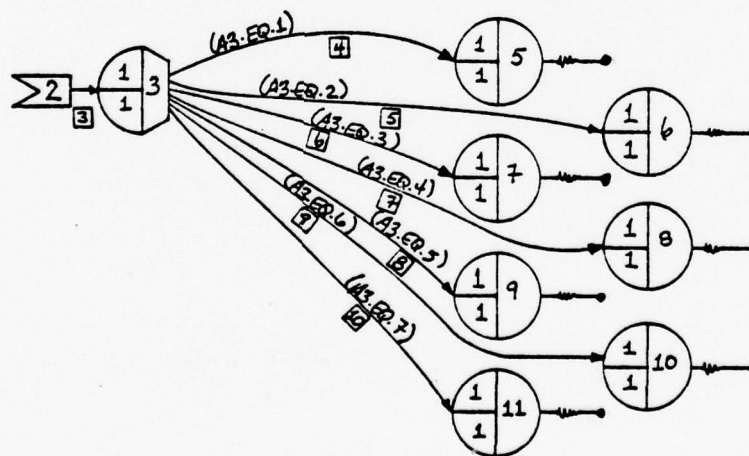
COURIER NODES

FIGURE 25

2. Courier Subnetwork

One regular node, seven sink nodes and seven
activities (Figure 25) routes courier messages to the seven
units involved in this study (three tank battalions, two
mechanized infantry battalions, one armored calvary squadron,
and one brigade main).

3. Radio Subnetwork

The nodes and activities in Figure 26 cause the
accumulation and sequencing of all O&I FM messages.

Messages are conditionally routed into regular
node 4 where attribute 11 (the match attribute) is set to
58 for each message. Queue node 14 is "blocked" and all
O&I messages accumulate and are ranked according to the
smallest value of attribute nine -- the time a radio
operator starts to transmit a message if the radio net is
clear.

Queue node 14 is not released until a match occurs
on attribute 11 in queue node 25. This procedure is similar
to the courier network described in Chapter II with two
exceptions; the source node 24 calls user function 3
(Figure 27) to determine when a transaction is routed to
queue node 25 and matching occurs on the same value of
attribute 11 for each message.
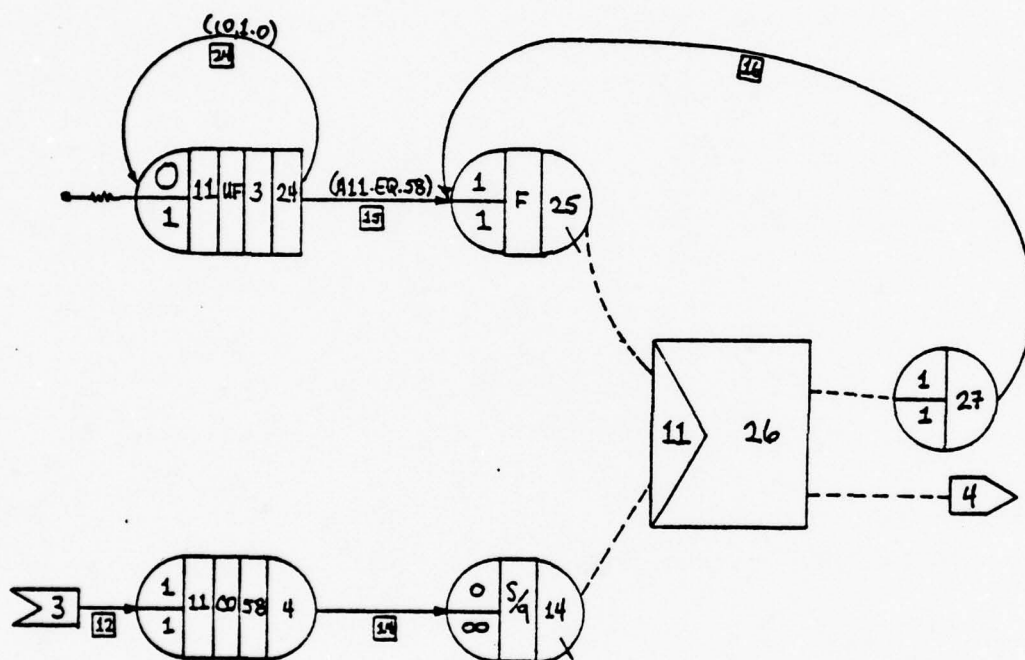
FIGURE 26

User Function 3

```
3 IF(NREL(14).EQ.58) UF=58
  RETURN
```

Figure 27

When all the O&I messages are in queue node 14, user function 3 sets attribute 11 to 58; whereupon a transaction is allowed to pass to queue node 25. A match occurs on attribute 11 and the match network allows each message to pass into the "exit-4" symbol without time penalty.

In summary, all O&I FM messages accumulate and are prioritized in queue node 14. When the last O&I message arrives in and is ranked by the queue the matching process is initiated. The message with the smallest value of attribute nine is allowed to pass, and so on until the queue is emptied.

The final set of nodes, activities and servers (Figure 28) graph a routine simulating a simplex radio net which delays a message until the net is clear of all ongoing transmissions.

Messages arrive in order of the smallest value of attribute nine (the time a message is available for transmission). Queue node 15 releases messages in a first-in, first-out (FIFO) order and user function six (Figure 29) assigns a server time.

SIMPLEX SIMULATION
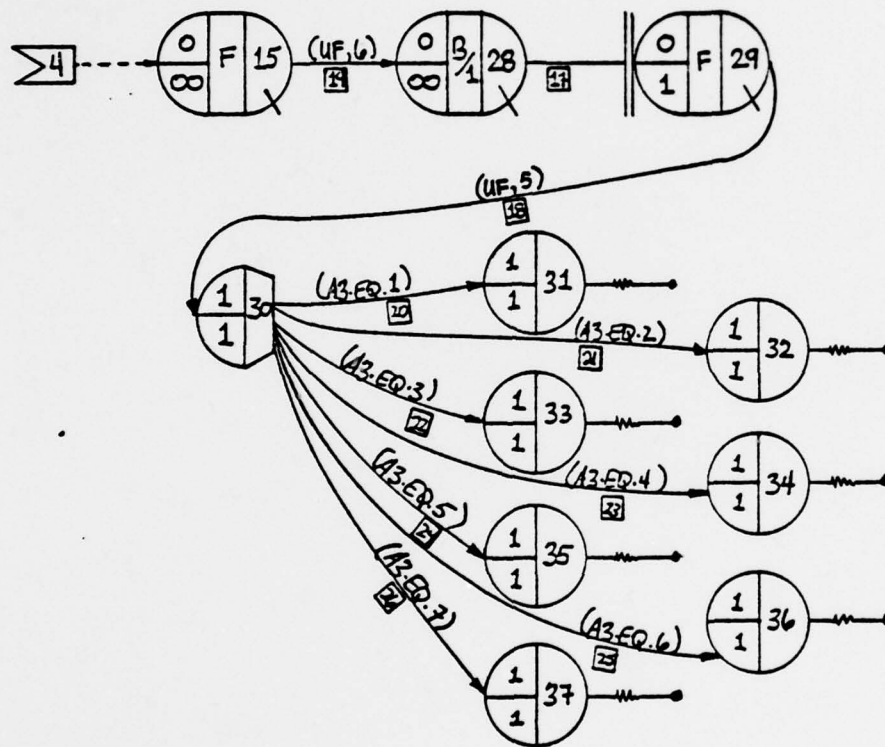
FIGURE 28

User Function 6

```
6 NT=NT+1
  AT9=GATBE(9)
  UF=AT9-ALAST
  ALAST=AT9
  WRITE(6,361) TNOW,UF
361 FORMAT(1X,F6.1,'--SIMULATION TIME',3X,F5.1,'--A9 DIFF')
  RETURN
```

Figure 29

Messages are routed without significant server or activity time to this point in the network. User function six starts the simulation clock and "spaces" the messages to simulate the availability of a message for transmission. The first message traversing server 19 receives a server time of AT9 found in the ninth attribute of this message. Subsequent messages receive a server time which is the difference between the preceding message's value of A9 (ALAST) and the current value of A9. This procedure synchronizes the messages with the simulation clock.

Queue nodes 28 and 29 and activity 18 perform a blocking function which simulates the delay caused by a simplex network. User function 5 (Figure 30) calculates and assigns the transmission time for the current message traversing server 18.

User Function 5

```
5 AT10=GATRB(10)
  AT9=GATRB(9)
  UF=AT10-AT9
  RETURN
```

Figure 30

Messages are allowed to pass into queue node 28; however, if server 18 is busy, they wait in the queue where the delay is assigned. Server 17 gives priority to the largest value of attribute one (precedence) if two or more messages accumulate in queue 28 while server 18 is busy. Regular node 30 routes messages to unit sink nodes according to the values of attribute three (the address attribute).

In summary, the interface routine routes messages according to the address and means of transmission. Those messages which are sent via the FM O&I net are sequenced with respect to TNOW and attribute nine and a delay time is assigned through a queue blocking procedure.

IV. MODEL ANALYSIS

A. INTRODUCTION

The first section of this chapter will explore the flexibility of Q-GERT in the modeling of the brigade routine. It will investigate interesting situations which arose in the model after modifying the brigade topology (unit topologies are excluded since they are essentially the same as the brigade). The last section will present the results of the interface routine. Percentages derived from the COMSR, and from the author's experiences with a brigade, will be used to establish different message genera- tion rates and different means specifications.

B. THE BRIGADE TOPOLOGY

This section is presented in three parts. Each part addresses one particular simulation run.

1. First Simulation Run

Table 6 includes the initial specifications (derived from COMSR) used in the first run of the Brigade main topology. These numbers relate to messages generated from the brigade main to the maneuver units.

Initial Specifications (COMSR)

Message generation rates (exponential)

    routine $\bar{x}$ = 6.13 min.

    priority $\bar{x}$ = 36.

    immediate $\bar{x}$ = 144.

Percent to record traffic means   11%

Percent to Voice   89%

Percent of record traffic to RATT   100%

Percent of record traffic to courier   0%

Message lengths

    Voice (normal) $\bar{x}$ = 391, SD = 29.04

    Record (uniform) min. = 225, max. = 275

Brigade move every 300. - 420. minutes

Brigade move time 60. - 120. minutes

Table 6

Table 7 summarizes traffic generation and unit movement for a brigade main run which is included in Appendix F.

Brigade Main Run Summary

512 messages were generated in 3000 simulation minutes
    (22 days)

    - 429 routine messages

    - 66 priority messages

    - 17 immediate messages

 50 messages routed to record traffic means

473 messages routed to voice means

 62 messages routed to RATT means

 73 messages routed to courier

  6 Brigade main CP displacements

    - each move occurring on the average of every
      443 minutes (7 1/2 hrs.)

    - each move lasting on the average of 82 minutes

Table 7

Table 8 summarizes interesting statistics collected on queues and sink nodes:

Statistics Collection (first-run)

Node number/type	Description	Remark
25/queue	message center clerk	1.5 min. average waiting time per message, server busy 22.5%
14/queue	courier queue	319.9 minutes between courier dispatches
67/sink	courier sink	459.5 minutes average delivery time, 62 messages delivered
6/queue	radio operator A&L net	32.9 minutes average waiting time per message, server busy 81.5%, 1 messages currently in queue
47/queue	radio operator O&I net	61.9 minutes average waiting time per message, server busy 89.3%, 8 messages currently in queue
10/sink	A&L FM sink	74.8 minutes average delivery time per message, 102 messages delivered
59/sink	successfully jammed FM trans- mission (unit stationary)	87 messages successfully jammed
62/sink	O&I FM sink	107.2 minutes average delivery time per message, 183 messages delivered
49,53/queues	FM voice blocking queues (when unit moving)	46.4 minutes average waiting time per message, server busy 47.5%
61/sink	successfully jammed FM trans- missions (unit moving)	23 messages successfully jammed
45/queue	RATT operator	3.1 minutes average waiting time per message, server busy 20.8%
52/sink	RATT sink	65.7 minutes average delivery time per message, 28 messages sent
44/regular node	RATT messages jammed	19 messages re-sent or transferred to courier

Table 8

The following observations/conclusions are made regarding the first simulation run of the communications generated from the brigade mains.

- a conservative amount of traffic is generated when the computed mean COMSR interarrival time is used as the mean for the exponential interarrival time. Five hundred and twelve messages were generated; whereas, COMSR predicts 573 (COMSR predicts 275 for a 24 hour period or 573 for a 3000 minutes period).

- a courier is necessary when a unit is exposed to enemy jamming. Seventy three messages are transferred to the courier as jamming in the RATT or FM voice routines prevents their transmission. (It should be noted that some messages are in the network at termination and are not included in sink statistics.)

- table 9 relates the effectiveness of the communications means indicated:

Communications Effectiveness

Means	Waiting Time	Ave. Delivery Time
Courier	319.9 min.	459.5 min.
A&L net	32.9	74.8
O&I net	61.9	107.2
RATT net	3.1	65.7

NOTE: The O&I net has a longer average delivery time than the A&L because all FM voice messages are routed via this means during a unit move. The RATT net has a low waiting and delivery time due to its low usage.

Table 9

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- the server utilization from the FM voice queues is excessive. Both FM nets are active more than 80% of the time with outgoing messages. This situation is obviously very critical when considering incoming messages not modeled in this study.

2. Second Simulation Run

Table 10 lists the changes made to the brigade main topology prior to the second simulation. (note: unless specified, the parameters in the first simulation run remain unchanged.)

Topology Changes: For Second Run

Item	Remark
message generation	rate doubled for each precedence category
	Routine $\overline{x}$ = 3.0 min.
	Priority $\overline{x}$ = 18.0
	Immediate $\overline{x}$ = 72.0
message length	messages shortened (to jamming threshold)
	voice $\overline{x}$ = 45 words
	RATT $\overline{x}$ = 33 words

Table 10

Table 11 summarizes significant model output.
(Note: due to conditions which will be mentioned, this job prematurely terminated in 2880 minutes simulation time.)

Model Output: Second Run

734 messages generated

- 577 routine

- 126 priority

- 31 immediate

 78 messages routed to record traffic means

622 messages routed to voice means

 93 messages routed to RATT means

Table 11

Table 12 summarizes interesting statistics collected
at queues and sink nodes. (Note: see node description in
first run summary.)

Statistics Collection (Second Run)

Node Number/type	Remark
6/queue	215 messages serviced, however server is at 100% and balking starts
47/queue	215 messages serviced, however server is at 100% and balking starts
45/queue	77 messages serviced, server less than 100%

Table 12

Messages arrive into queue nodes 6 and 47 at such a
rapid rate that the queue servers are occupied 100% of the

time. As a result, an excess of messages accumulates in the queue and the Q-GERT simulation prematurely terminates. This models the failure of the FM voice network when 89% of all traffic is routed to this means at the given rate.

3. Third Simulation Run

Table 13 lists the changes made to the brigade topology prior to the third simulation which is included in Appendix F. (Note: the accelerated rate and shortened message lengths are not changed from the previous simulation.)

Topology Changes: For Third Run

25% of traffic routed to record means

75% of traffic to voice means

50% by courier

50% by RATT

Table 13

Table 14 summarizes interesting statistics collected at queue and sink nodes when 765 messages are generated in 3000 minutes simulation time. (Note: see node description in first run summary.)

Statistics Collection (Third Run)

Node number/type	Remarks
25/queue	26.4 average waiting time per message Server busy 89.9% (MSG CTR QUEUE)
14/queue	147.4 minutes between courier dispatches (courier queue)
67/sink	236.4 minutes average delivery time, 171 messages delivered (courier, sink)
6 queue	52.1 minutes average waiting time per message. Server busy 92.3% (A&L operator)
47 queue	61.6 minutes average waiting time per message. Server busy 98.7% (O&I operator)
10/sink	90.8 minutes average delivery time per message (A&L sink)
62/sink	116.9 minutes average delivery time per message. 219 messages delivered (O&I sink)
61,59/sinks	81 messages successfully jammed

Table 14

Distributing traffic more evenly among communications means eliminates the explosive situation discovered in the previous simulation run; however, the servers are all near 90% active.

In summary, the three simulation runs show the response of the brigade main model to different message generation rates and different means specifications.

The first simulation run demonstrates the danger of transmitting excessively long messages. One hundred and ten

messages or 21.5% of all messages generated are successfully
jammed. The general rules which "decide" if a message is
successfully jammed are message length and probability.
An analyst can easily adjust these rules to conform to a
change in threat and predict the resultant success of com-
munications for a unit. The first simulation also provides
insight into communications failure when a unit does not
properly employ available communications means. The FM
voice radio operators are busy in excess of 80% of the time,
whereas the RATT operator is busy 20.8% of the time. This
may be evidence to reevaluate current communications doc-
trine which directs that certain nets are information
specific (such as an operations intelligence net). Perhaps
there is a need to employ communications nets or means
based on traffic loading rather than by message content.

The second simulation corroborates a belief of the
author that communication systems usually fail because
conventional tactical units generate on excessive amount
of (usually inconsequential) communications. The failure
is manifested in message overloading in a message center or
in a overworked radio operator, or in an overloaded, under-
maintained, piece of radio equipment. The brigade model
when "properly" loaded could predict communications equipment
and personnel needs and assist in determining maintenance
schedules as well as demonstrate the consequence of system
experimentation.

The final simulation displays the impact of a heavily loaded communications network where traffic is more equitably routed than in previous simulations. This run generates and routes an excessive quantity of messages (near explosive) which simulates the upper bound of the unit's communications capability. The brigade model could be used to predict the number of attachments a communications system could accommodate or to calculate a potential unused communications capacity.

C. THE INTERFACE ROUTINE

This routine was exercised for 1000 simulation minutes using 184 data cards generated from the unit simulation runs (see Appendix E). The purpose of this routine was to sort messages according to communications means and message address and to compute an average message delay for radio messages. This routine was severely limited due to the concurrent transaction restraint.

One hundred and eighty five cards were "read-in" at node one and 184 messages were inserted into the network at node two. Fifty five messages were routed to the courier sinks, 19 to the A&L sink, 52 to the RATT sink and 58 to the O&I network.

The 58 messages traversed this network to their respective address sinks and an average of 18.7 minutes delay per message was computed. This delay represents the average amount of time a radio operator has to wait for a clear net.

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This time should be added to the average O&I message delivery time described in part one of the preceding section.

This routine illustrates another facet of Q-GERT which provides the analyst with more modeling flexibility. The output of another model can be used as input for a Q-GERT model. Therefore, an analyst can use a Q-GERT network as a "subroutine" in conjunction with a larger model such as the STAR model currently in evolution at the Naval Postgraduate School.

V. CONCLUSIONS AND RECOMMENDATIONS

This chapter is divided into three sections. The first section addresses the advantages of Q-GERT, the second, the disadvantages, and the third conclusions and recommendations.

A. ADVANTAGES OF Q-GERT

The modeling of a system is made easier if a pictoral or graphical representations is made of the system and if a manager models only critical variables. The process of culling-out the non-essential variables and then the graphing of the remaining key variables often provides the manager variable interrelationships serendipitously. Studying the interrelationships graphed often results in the discovery of additional variables which make the model more representative.

The network approach, in modeling a system with Q-GERT, provides an appealing method for communicating ideas effec-tively. The Q-GERT symbolism is sufficiently descriptive that a network is almost self-explanatory. The manager can therefore easily communicate the essential features of a network since the graphed concepts are transparent to the audience. If concepts are quickly grasped by superiors then required changes or additions to the model are more likely to be completed early-on in the evolution of the model. The end product is a more accurate model requiring less of the manager's time.

A complex system such as a communications network is easily presented for briefing when decomposed into identifiable subsystems. The graphing and computer simulation of incremental portions of the network assists the manager in identifying and correcting errors. Graphically, subsystems are easily linked for briefing purposes to neighboring subsystems with special user unique symbols. Additionally, if necessary, the output of one subsystem may be punched on cards and used as input for a subsequent subsystem.

The flexibility of Q-GERT permits effective analysis of a smaller complex system under a variety of conditions. Unlike "PERT" or "CPM" procedures, Q-GERT provides the following capabilities:

- activities can be performed on a conditional basis, e.g., if a message is addressed for unit "x", route it on activity "y".

- activity times can be selected probabilistically from one of 11 probability distributions.

- activities can be performed given a probability of being accomplished; e.g., "thirty percent of the messages are routed via activity "y"'.

- the dynamic aspect of a system can be modeled by the appropriate creation, modification and destruction of transactions or messages. Also the movement of a message through the topology may be governed by the use of probabilistic or deterministic branching, matching, and queuing using ranking rules.

User written FORTRAN inserts provide the user, who has a working knowledge of FORTRAN, the flexibility to specify service or activity times on transactions passing through an activity and to set attributes based on user determined conditions.

B. DISADVANTAGES OF Q-GERT

The 100 node/100 arc Q-GERT analysis package does not provide the manager with the sufficient flexibility to model involved networks accurately. A summary of the most critical limitations of this smaller routine include:

number of nodes - 100

number of arcs - 100

number of Q-nodes and S-nodes - 50

number of source nodes - 20

number of concurrent activities - 200

number of concurrent transactions - 130
    (based on 11 + 1 attributes per messages)

number of parameter sets - 100

These limitations are a function of array sizes for variables within Q-GERT subroutines. Most managers are not sufficiently fluent in FORTRAN to easily reconstruct an analysis package to satisfy a certain situation.

The process of decomposing a large network, conducting computer runs on subnetworks and then interfacing outputs might result in a misrepresentation of the system. An example of an inaccurately modeled situation is the simplex

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radio net of this model. The emptying of the outgoing

message queue is a function of the radio operator's message

handling time, the amount of traffic on the radio net,

message lengths, and interference. The interfacing routine

models the amount of time an operator waits for a clear net;

however, it does not accurately model the radio operator's

message handling time since it is a function of both

incoming and outgoing messages which are necessarily

modeled separately. A more accurate representation of a

simplex net would be possible with a larger Q-GERT capability.

Q-GERT does provide the modeler with a variety of symbols

to allow the modeling of a wide class of problems without

requiring programming background or use by the manager.

However, relying exclusively on Q-GERT symbolism to model

even a moderately complex network will result in a confusing

and elaborate network which probably will not model the

situation accurately.

C. CONCLUSIONS AND RECOMMENDATIONS

Q-GERT is a viable modeling and analysis tool for a

manager in the military community. It must be quickly added

that the manager must have a working knowledge of FORTRAN

and have the larger Q-GERT package available to adequately

model the complex problems facing the military today.

Q-GERT is ideal for model presentation when the audience

does not have an analytical background. Complex concepts

are relatively easy to graph and to represent with Q-GERT

symbols. If the audience follows the "flow" of the model logic, then the credibility of the model and the manager is established.

The 100 node/100 arc Q-GERT analysis program is inadequate for modeling large involved communication networks. This small routine is adequate to model specific aspects of communications such as the FM voice communications in a given unit or perhaps the microwave communications within a division. More involved and encompassing networks such as the communications within a mechanized brigade covering force must be modeled using the 1000 node/1000 arc routine.

The conclusion of this study is that the smaller Q-GERT package can not accurately model the communications of a brigade sized covering force. Q-GERT, however, is easily used and understood by managers having a limited FORTRAN vocabulary. A Q-GERT model is a flexible, easily modified, and convenient analysis tool.

The author recommends that the 1000 node/1000 arc Q-GERT analysis program be used to model the communications of a brigade covering force. Additionally, it is recommended that Q-GERT be considered for other military analysis such as doctrine modification, and systems requirements determination.

APPENDIX A

SUMMARY OF BASIC Q-GERT SYMBOLS [6]

DEFINITION
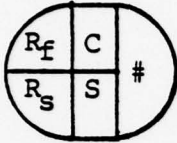
R_f is the number of incoming transactions required to release the node for the first time

R_s is the number of incoming transactions required to release the node for all subsequent times
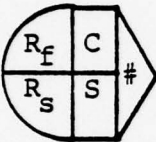
C is the criterion for holding the attribute set at a node (optional)

S is the statistic collection type or marking (optional)

\# is the node number
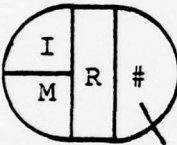
I is the initial number of transactions at the Q-node

M is the maximum number of transactions permitted at the Q-node

R is the ranking procedure for ordering transactions at the Q-node

\# is the Q-node number
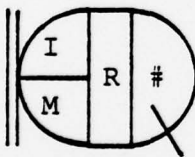
Blocking indicator (causes preceding service activity to hold transactions)
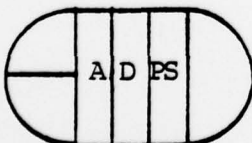
A is the attribute number to which a value is to be assigned ("A -" specifies subtract value from attribute A)

D Distribution or function from which assignment value is to be determined

PS Parameter Set

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\# match node number

A is the attribute number on which the match is made

transactions in Q-node N/1 are routed to Q-node N/3 and Q-node N/2 transactions are routed to Q-node N/4 when attribute value is matched
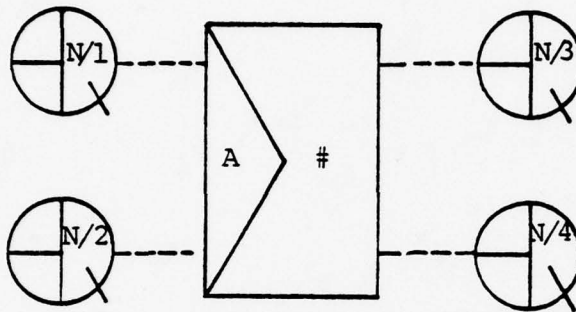
indicates deterministic branching from a node

indicates probabilistic branching from a node

indicates conditioned-take first branching from a node

indicates conditioned-take all branching from a node

—⟋M⟍→ Pointer to a source node or
from a sink node
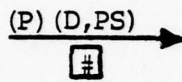
(P) (D,PS) P is the probability of taking
[#] the activity (only used if
probabilistic branching from the
start node of the activity
specified)

D is the probability distribution,
or function from which the
activity time is to be determined

PS is the user defined parameter
set for D, or a constant value

   is an activity number
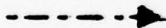
- - - -▶ Balking route from a Q-node

APPENDIX B

USER FUNCTIONS

A modeler may "insert" user functions at the start of an activity and at a node. User functions are called at nodes to perform mathematical operations, assign values to attributes, halt or start activities, modify a node in the network, etc. At the start of an activity, user functions are usually used to specify the time to perform the service on a message passing through an activity. Figure 31 shows the preamble for the user function subprogram.

User Function Preamble

```
      FUNCTION UF(IFN)
C*******BRIGADE MAIN USER FUNCTIONS
      COMMON/QVAR/NDE,NFTBU(100),NREL(100),NRELP(100),
     1 NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
      A1=GATRB(1)
      A2=GATRB(2)
      A3=GATRB(3)
      A4=GATRB(4)
      A5=GATRB(5)
      A6=GATRB(6)
      A7=GATRB(7)
      A8=GATRB(8)
      A9=GATRB(9)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,
     1 19,20,21,22,23),IFN
```

Figure 31

IFN is used in the subprogram UF to differentiate from among the possible calls to UF at different locations in the topology. In this way, function UF contains all the

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FORTRAN coded inserts used in the model. The common block
includes those Q-GERT variables which are necessary for the
basic Q-GERT program to operate. The function GATRB(J) is
called to assign the value of the jth attribute to the
variable A(J) of the transaction currently being processed.

APPENDIX C

EXTRACT OF THE COMSR DATA BASE

Discussion: The COMSR report lists the expected
traffic between TUN units for a 24 hour period. For this
study the data base is modified so message lengths are
measured in a standard of words per message. The left-hand
side of Table 15 identifies if a message is transmitted or
received by the TUN unit depicted in the column headings.
Messages are categorized by precedence and means.

Message Flow from the Brigade Main
to Unit Indicated

| | Tank Batallion | | | Mechanized Batallion | | Squadron |
	Voice	Page	Pouch	Voice	Page	Voice
ROUTINE						
X	27	10	15	26	1	
L	46	23		82	2	
	1.7	2.3		3.15	2	
	192*	575**		356	500	
R	39	6		42	6	4
L	142	6		143	6	16
	3.64	1		3.4	1	4
	411	250		384	250	432
PRIORITY						
X	28	7		12	4	
L	41	12		41	8	
	1.46	1.7		3.42	2	
	165	425		369	500	
R	7			9		1
L	20			28		5
	2.86			3.11		5
	323			351		540
IMMEDIATE						
X	14			2		
L	9			5		
	.643			2.5		
	73			283		
R						
L						

Table 15

*27 messages, 46 minute total transmission time, 1.7 minues average message transmission time, 192 words per average message.

**10 messages, 23 pages total, 2.3 page average message length, 575 words per average page.

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Tables 16 through 20 summarize the data presented in Table 15. This information is used to establish branching rules, determine message interarrival times and generate message lengths for the Q-GERT program.

MESSAGE GENERATE FROM BDE TO
ALL MANEUVER UNITS OF TASK FORCE

235 Routine   85%

40 Priority   15%

0 Immediate   0%

Table 16

WEIGHTED MESSAGE LENGTH BY VOICE, AND
PAGE FROM BRIGADE TO TASK FORCE

Voice   -   391 words, SD = 29.04, Min 323, Max 540
Page   -   250 words, SD = 0, Min 250, Max 250

Table 17

MEANS OF COMMUNICATING TRAFFIC FROM
BRIGADE MAIN TO TASK FORCE

245 Voice   89%

30 Page   11%

0 Courier   0%

Table 18

MESSAGE GENERATION RATE BY PRECEDENCE

TYPE	Rate (#/24 hrs)	Ave. Interval	(Ave -30%)	(Ave +30%)
Routine	235	6.13 min.	4.291	7.969
Priority	40	36	25.2	46.8
Immediate	0	0	0	0

Table 19

MESSAGE GENERATION FROM BRIGADE
TO UNIT INDICATED

	Total # per BN	Total for Task Force	
TK BN (3 ea)	52	156	19%/BN
MECH BN (2 ea)	57	114	20%/BN
Squadron (1 ea)	5	5	3%

Table 20

BRIGADE TOPOLOGY
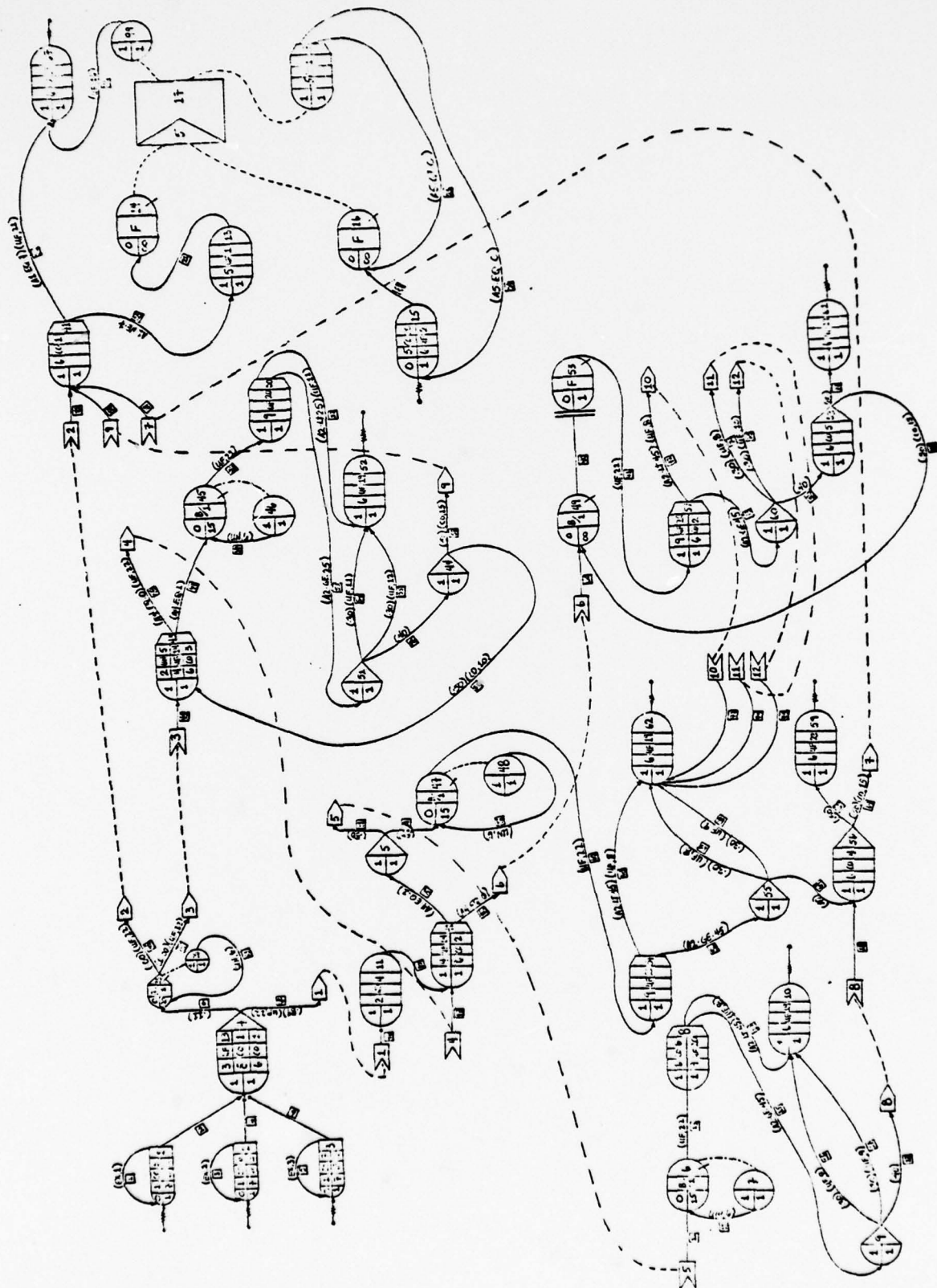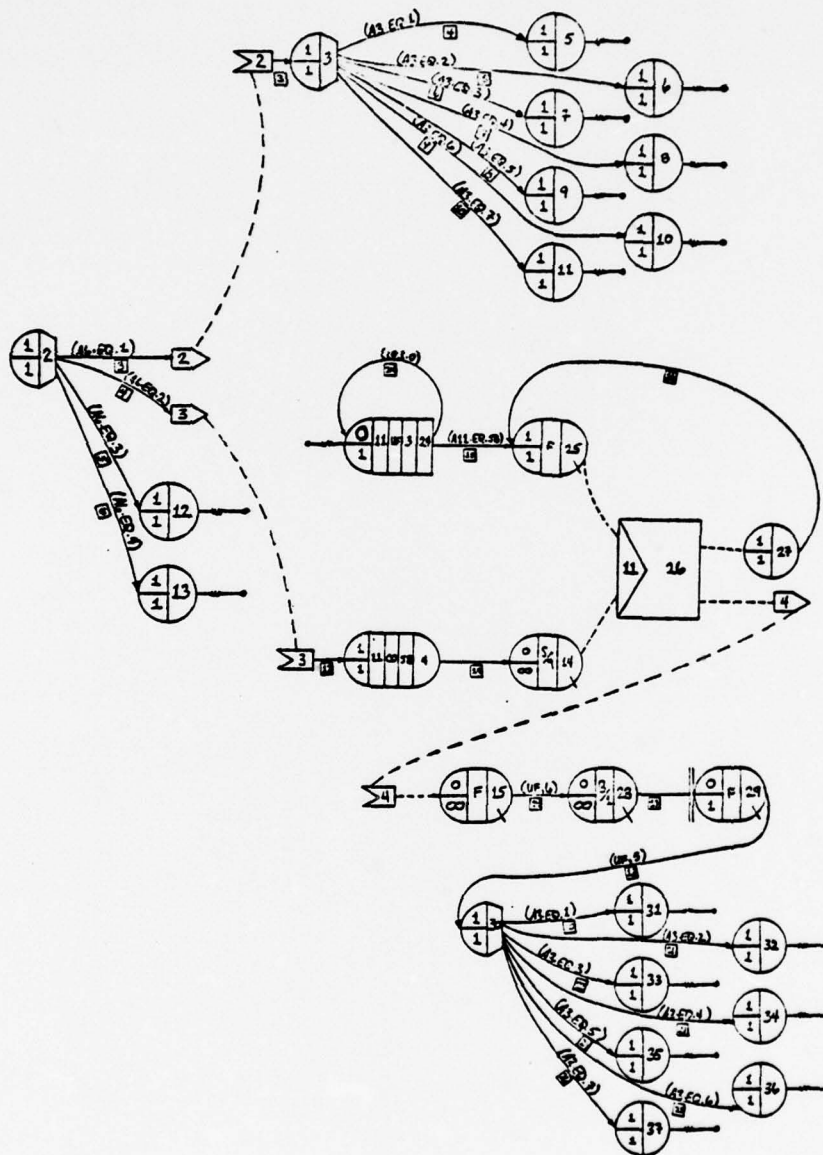
APPENDIX F

BRIGADE COMPUTER MODEL AND OUTPUT

(model)

```
      FUNCTION UF(IFN)
C*******BRIGADE MAIN USER FUNCTIONS
      COMMON/QVAR/NDE,NFTBU(100),NREL(100),NRELP(100),
     1 NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
      A1=GATRB(1)
      A2=GATRB(2)
      A3=GATRB(3)
      A4=GATRB(4)
      A5=GATRB(5)
      A6=GATRB(6)
      A7=GATRB(7)
      A8=GATRB(8)
      A9=GATRB(9)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,
     1 19,20,21,22,23),IFN
    1 NPS=NPS+1
      UF=NPS
      RETURN
    2 UF=0
      NPS=0
      RETURN
    3 WRITE(6,50) NREL(25)
   50 FORMAT(1X,F4.0)
C******UF3 USED TO CHECK NO. IN QUEUE 25
      RETURN
    4 WRITE(6,60) A1
   60 FORMAT(1X,F2.0)
C******UF4 USED TO CHECK VALUE OF ATTRIBUTE 1(PRECIDENCE)
      RETURN
    5 WRITE (6,70) A2
   70 FORMAT(1X,F4.0)
C******UF5 USED TO CHECK VALUE OF ATTRIBUTE 2(MSG LENGTH)
      RETURN
    6 WRITE(6,80) A7
   80 FORMAT(1X,F2.0)
C******UF6 USED TO CHECK VALUE OF ATTRIBUTE 7(ADDRESSEE)
      RETURN
    7 WRITE(6,90) A8
   90 FORMAT(1X,F2.0)
C******UF7 USED TO CHECK VALUE OF ATTRIBUTE 8(SINK)
      RETURN
    8 UF=(A2/113)+10
      RETURN
    9 UF=(A2/113)*2+10
      RETURN
   10 UF=(A2/113)*1.5+10
      RETURN
   11 UF=((A2/60)+(A2/40)+10)
      RETURN
   12 UF=((A2/60)*3+(A2/40)+10)
      RETURN
   13 UF=0
      RN=DRAND(1)
      IF(RN.GT..00.AND.RN.LE..19) UF=1
      IF(RN.GT..19.AND.RN.LE..38) UF=2
      IF(RN.GT..38.AND.RN.LE..57) UF=3
      IF(RN.GT..57.AND.RN.LE..77) UF=4
      IF(RN.GT..77.AND.RN.LE..97) UF=5
      IF(RN.GT..97.AND.RN.LE.1.0) UF=6
      RETURN
   14 IF(DUMMY.EQ.0.) GO TO 88
      IF(DY.EQ.0) GO TO 87
      SAMP1=UN(7)
      DY=0
      TMOVE=SAMP1+TNOW
   87 IF(TNOW.LE.TMOVE) GO TO 99
      SAMP2=UN(8)
      TSTOP=TMOVE+SAMP2
   88 IF(TNOW.GE.TSTOP) GO TO 99
      DUMMY=0
      UF=0
      WRITE(6,260) TNOW,TMOVE,TSTOP,SAMP1,SAMP2
  260 FORMAT(1X,5(F5.0,1X),1X,' MOVING ')
```

99

```
      RETURN
   99 IF(TNCW.GE.TSTOP) DY=1
      DUMMY=1
      UF=1
      WRITE(6,160) TNOW,TMOVE,TSTOP,SAMP1,SAMP2
  160 FORMAT(1X,5(F5.0,1X),1X,' STATIONARY ')
      TSTOP=3000.
      RETURN
   15 WRITE(6,100) A4
  100 FORMAT(1X,F2.0)
C******UF15 USED TO CHECK VALUE OF ATTRIBUTE 4(MOVE)
      RETURN
   16 IF(A5.EQ.1) GO TO 300
      UF=DT
      RETURN
  300 DT=UN(9)
      UF=DT
      RETURN
   17 TMOVE=0
      NPS=0
      TSTOP=3000
      DY=1
      DUMMY=1
      TIME=C
      SAMP1=0
      SAMP2=0
      RETURN
   18 WRITE(6,110) NREL(14)
  110 FORMAT(1X,F3.0)
C******UF18 USED TO CHECK NO.IN COURIER QUEUE
      RETURN
   19 UF=1
      WRITE(6,555) TNOW,A7,A9,A1,A2,A3,A4,A5,A6,A8
  555 FORMAT(1X,3(F5.0,1X),1X,F2.0,1X,F4.0,1X,2(F2.0,1X),
     1 F3.0,1X,2(F2.0,1X))
      RETURN
   20 UF=TNCW
      RETURN
   21 TIME=UN(9)
      UF=TIME
      RETURN
   22 IF(A1.EQ.5) GO TO 1000
      RN=UN(10)
      UF=RN
      RETURN
 1000 RN=UN(11)
      UF=RN
      RETURN
   23 WRITE(6,566) TNOW,A7,A9,A1,A2,A3,A4,A5,A6,A8
  566 FORMAT(1X,3(F5.0,1X),1X,F2.0,1X,F4.0,1X,2(F2.0,1X),
     1 F3.0,1X,2(F2.0,1X))
      RETURN
      END
```

APPENDIX F (CONT.)
(Model)

```
*** INPUT CARDS ***
GEN,COBB,THESES,01,07,1979,,6,900,3000,1,F,,9*
SEE,1,CO8364C72/N*
SCU,24,0,1,A,M*
VAS,24,6,UF,17*
SOU,15,0,1,D,M*
VAS,15,5,CC,20.,6,UF,2*
PAR,1,6.13,4.291,7.969*
PAR,2,36,25.2,45.8*
PAR,3,144,36,252*
PAR,4,391,323,540,29.04*
PAR,5,,225,275*
PAR,6,,5.,10.*
PAR,7,,300.,420.*
PAR,8,,60.,120.*
PAR,9,,20.,80.*
PAR,10,,5.,10.*
PAR,11,,10.,20.*
SOU,1,0,1,A,M*
SOU,2,0,1,A,M*
SOU,3,0,1,A,M*
VAS,1,1,CO,5.,7,UF,20*
VAS,2,1,CC,6.,7,UF,20*
VAS,3,1,CC,7.,7,UF,20*
ACT,1,1,PC,1,1*
ACT,2,2,PC,2,3*
ACT,3,3,PC,3,5*
REG,4,1,1,P*
VAS,4,3,UF,13,8,CO,1.*
ACT,1,4,,,2*
ACT,2,4,,,4*
ACT,3,4,,,6*
QUE,25,0,20,P,8/1,26*
ACT,4,25,,,7,,.11*
REG,26,1,1,D*
ACT,26,25,UN,6,43*
REG,41,1,1,F*
VAS,41,6,CC,1*
REG,12,1,1,D*
VAS,12,2,CO,500.*
ACT,25,12,UF,22,45,,.00*
ACT,12,41,,,99*
REG,42,1,1,F*
VAS,42,4,UF,14,6,CC,2.*
REG,11,1,1,D*
VAS,11,2,NC,4*
ACT,11,42,,,100*
ACT,4,11,UF,22,46,,.89*
QUE,47,0,15,D,8/1,48*
REG,48,1,1,D*
REG,5,1,1,P*
ACT,42,5,,,59,,,A4.EQ.1*
ACT,5,47,,,10,,.50*
QUE,6,0,15,D,8/1,7*
ACT,5,6,,,11,,.50*
REG,7,1,1,D*
ACT,7,6,UN,6,12*
REG,8,1,1,F*
VAS,8,6,CC,6.,9,UF,20*
ACT,6,8,UF,22,13*
REG,9,1,1,P*
```

101

```
SIN,10,1,1,D,I*
VAS,10,6,UF,19*
ACT,8,10,LF,3,14,,,A2.LT.45.*
ACT,8,9,,,15,,,A2.GE.45.*
ACT,9,10,UF,8,16,,.30*
ACT,9,10,UF,9,17,,.30*
ACT,9,56,,,18,,,40*
ACT,48,47,UN,6,61*
REG,54,1,1,F*
VAS,54,9,UF,20*
ACT,47,54,LF,22.,62*
REG,55,1,1,P*
ACT,54,55,CC,0.,64*
SIN,62,1,1,D,I*
VAS,62,6,UF,19*
ACT,54,62,UF,8,63,,,A2.LT.45.*
ACT,55,62,LF,8,65,,.30*
ACT,55,62,UF,9,66,,.30*
REG,56,1,1,F*
VAS,56,6,CO,4*
ACT,55,56,CO,0.,67,,.40*
SIN,59,1,1,,I*
VAS,59,6,UF,23*
ACT,56,59,,,68,,.50*
ACT,56,41,CC,15.,69,,.50*
QUE,49,0,,D,B/1*
ACT,42,49,CC,0.,60,,,A4.EQ.0*
QUE,53,0,1,D,F,8*
ACT,49,53,,,70*
REG,57,1,1,F*
VAS,57,9,UF,20,6,CO,2*
ACT,53,57,UF,22,71*
REG,60,1,1,F*
ACT,57,60,CO,0.,73,,,A2.GE.45.*
ACT,60,62,UF,8,74,,.30*
ACT,60,62,LF,10,75,,.30*
ACT,57,62,UF,8,72,,,A2.LT.45.*
REG,58,1,1,P*
VAS,58,6,CO,5*
ACT,60,58,CC,0.,76,,.40*
SIN,61,1,1,D,I*
VAS,61,6,UF,23*
ACT,58,61,,,77,,.50*
ACT,58,49,CC,15.,78,,.50*
REG,43,1,1,F*
VAS,43,4,UF,14,6,CO,3,2,UN,5*
ACT,25,43,LF,22.,45,,.50*
ACT,43,42,UF,22.,48,,,A4.EQ.0*
CUE,45,0,15,D,B/1,46*
REG,46,1,1*
ACT,43,45,,,49,,,A4.EQ.1*
ACT,46,45,UN,6,50*
REG,50,1,1,F*
VAS,50,9,UF,20*
ACT,45,50,UF,22,51*
SIN,52,1,1,D,I*
VAS,52,6,UF,19*
ACT,50,52,LF,11,52,,,A2.LT.25.*
REG,51,1,1,P*
ACT,50,51,CC,0.,53,,,A2.GE.25.*
ACT,51,52,LF,11,54,,.30*
ACT,51,52,UF,12,55,,.30*
REG,44,1,1,F*
```

APPENDIX F (CONT.)

(Model)

```
REG,44,1,1,F*
ACT,51,44,CC,C.,56,,.4C*
ACT,44,43,CO,10.,57,,.50*
ACT,44,41,CC,15.,58,,.50*
SIN,67,1,1,D,I*
VAS,67,6,UF,19*
ACT,41,67,LF,21,81,,,A1.EC.7.*
REG,13,1,1,D*
VAS,13,5,UF,1*
ACT,41,13,,,80,,,A1.NE.7*
QUE,14,0,(10)17*
VAS,14,6,CC,1*
ACT,13,14,,,21*
QUE,16,0,(10)17*
ACT,15,16,,,22*
REG,18,1,1,F*
VAS,18,5-,CC,1.*
REG,99,1,1,D*
ACT,99,67,UF,16,98*
MAT,17,5,14/99,16/18*
ACT,18,15,,,24,,,A5.EQ.0*
ACT,18,16,,,23,,,A5.GT.0.*
FIN*
```

GERT SIMULATION PROJECT THESES BY COBB
DATE 1/ 7/ 1979

RESULTS FOR RUN   1

ELAPSED TIME FOR RUN = 3000.0000

NODE STATISTICS

NODE	LABEL	AVE.	NO OF OBS.	TYPE OF STATISTICS
10		74.7572	102.	I
62		1C7.1799	183.	I
59		80.4446	87.	I
61		1C7.8055	23.	I
52		65.7081	28.	I
67		453.7161	44.	I

NUMBER IN Q-NODE   **** WAITING TIME **** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
25		C.0253	0.	2.	0	1.5161
47		4.2961	0.	14.	8	61.9632
6		1.9502	0.	9.	1	32.8679
49		1.1590	0.	11.	0	34.0851
53		0.4241	0.	1.	0	12.4731
45		0.0492	0.	2.	0	3.0757
14		7.5700	0.	19.	11	319.8579
16		1.0000	0.	1.	1	49.18C3

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
45		1	0.2370	190.7378	54.2312
62		1	0.8930	119.5730	1395.4749
13		1	0.8153	107.5557	652.9722
70		1SERVER NEVER USED			
71		1	0.4754	373.0835	288.4187
51		1	0.2080	363.9497	87.3789

BLOCKED TIME PER UNIT TIME

SERVER	LABEL	AVE.	LONGEST PERIOD BLOCKED
70		0.3721	19.9954

NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
25		0.0
47		0.0
6		C.0
45		0.0

APPENDIX F (CONT.)

(first run)

FINAL RESULTS FOR FIRST SIMULATION

TOTAL ELAPSED TIME = 3000.0000

NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO. OF OBS.	STAT TYPE
10		74.7572	37.6122	102.	I
62		107.1799	57.3190	183.	I
59		80.4446	51.7093	87.	I
61		107.8055	56.9966	23.	I
52		65.7081	18.3461	28.	I
67		453.7161	245.0221	44.	I

NUMBER IN Q-NODE　　　　　　　　** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
25		0.0253	0.	2.	0	1.5161
47		4.2961	0.	14.	8	61.9632
6		1.9502	0.	9.	1	32.8679
49		1.1590	0.	11.	0	34.0891
53		0.4241	0.	1.	0	12.4731
45		0.0492	0.	2.	0	3.0757
14		7.5700	0.	19.	11	319.8579
16		1.0000	0.	1.	1	49.1803

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
45		1	0.2370	190.7378	54.2312
62		1	0.8930	119.5730	1395.4749
13		1	0.8153	107.5557	652.9722
70		1	0.0	373.0835	0.0
71		1	0.4754	373.0835	288.4187
51		1	0.2080	363.9497	87.3789

BLOCKED TIME PER UNIT TIME

SERVER	LABEL	AVE.	LONGEST PERIOD BLOCKED
70		0.3721	19.9954

NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
25		0.0
47		0.0
6		0.0
45		0.0

NODE	TRANSACTION PASSAGES
1	429
2	66
3	17
4	512
5	386
6	177
8	176
9	176
10	102
11	459
13	71
14	60
15	4
16	60
17	120
18	60
24	1
25	50
41	73
42	473
43	62
44	19
45	48
47	200
49	102
50	48
51	48
52	28
53	102
54	199
55	199
56	153
57	102
58	39
59	87
60	102
61	23
62	183
67	44
99	60

PRINTOUT OF ONGOING ACTIVITIES
AT   3000.00

ACTIVITY END TIME	END NODE	ACTIVITY NUMBER
3001.32	11	46
3001.66	11	46
3002.92	8	13
3003.00	1	1
3007.85	54	62
3008.17	52	55
3011.06	49	78
3012.00	3	5
3013.68	11	46
3036.00	2	3
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98
**********	67	98

GERT SIMULATION PROJECT THESES   BY COBB
DATE 1/ 7/1979

FINAL RESULTS FOR 1 SIMULATIONS

AVERAGE NODE STATISTICS

NODE LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	STAT TYPE
13	1.0000	74.7572	0.0	0.0	74.7572	74.7572	I
62	1.0000	107.1799	0.0	0.0	107.1799	107.1799	I
59	1.0000	80.4446	0.0	0.0	80.4446	80.4446	I
61	1.0000	107.8055	0.0	0.0	107.8055	107.8055	I
52	1.0000	65.7081	0.0	0.0	65.7081	65.7081	I
67	1.0000	453.7161	0.0	0.0	453.7161	453.7161	I

AVERAGE NUMBER IN Q-NODE

NUMBER IN Q-NODE

NODE LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.
25	0.0253	0.0	0.0	0.0253	0.0253	61.5161	0.0	0.0	2.0000
47	4.2961	0.0	0.0	4.2961	4.2961	32.8632	0.0	0.0	14.0000
6	1.5502	0.0	0.0	1.1590	1.9502	34.0891	0.0	0.0	11.0000
53	0.4241	0.0	0.0	0.4241	1.1590	12.4731	0.0	0.0	1.0000
42	0.0492	0.0	0.0	0.0492	0.0492	3.0757	0.0	0.0	2.0000
14	7.5700	0.0	0.0	7.5700	2.5700	318.8579	0.0	0.0	19.0000
16	1.0000	0.0	0.0	1.0000	1.0000	49.1803	0.0	0.0	1.0000

AVERAGE SERVER UTILIZATION

EXTREME VALUES

SERVER LABEL	NO. PARALLEL SERVERS	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	NO OF OBS.	MIN.	MAX.	STD.DEV.	SD OF AVE	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
45	1	0.2370	0.0	0.0	0.2370	0.2370	1.	0.2370	0.2370	0.0	0.0	150.7378	154.2412
62	1	0.6930	0.0	0.0	0.6930	0.6930	1.	0.8930	0.8930	0.0	0.0	109.5578	135.4749
13	1	0.8153	0.0	0.0	0.8153	0.8153	1.	0.8153	0.8153	0.0	0.0	107.5557	652.9722
70	1	0.4754	0.0	0.0	0.4754	0.4754	1.	0.4754	0.4754	0.0	0.0	372.0835	0.0
51	1	0.2080	0.3	0.0	0.2080	0.2080	1.	0.2080	0.2080	0.0	0.0	363.9497	288.4487
													87.3789

AVERAGE BLOCKED TIME PER UNIT TIME

BLOCKED TIME OF SERVER

SERVER LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	LONGEST PERIOD BLOCKED
70	0.3721	0.0	0.0	1.	0.3721	0.3721	19.9954

AVERAGE NO. BALKING PER UNIT TIME

NODE LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
25	0.0	0.0	0.0	1.	0.0	0.0
47	0.0	0.0	0.0	1.	0.0	0.0
45	0.0	0.0	0.0	1.	0.0	0.0

GERT SIMULATION PROJECT THESES   BY COBB
            DATE 1/ 7/ 1979

        FINAL RESULTS FOR FIRST SIMULATION

        TOTAL ELAPSED TIME =   3000.0000

            NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO OF OBS.	STAT TYPE
10		90.7774	51.0619	177.	I
62		116.9624	66.4370	219.	I
59		89.6510	55.5843	96.	I
61		129.5703	92.3059	15.	I
52				NO VALUES RECORDED	
67		236.4090	111.5943	171.	I

            NUMBER IN Q-NODE   ** WAITING TIME **
                                                         IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
25		1.7701	0.	7.	0	26.4193
47		4.5348	0.	12.	6	61.5580
6		3.8772	0.	13.	9	52.1601
49		3.0958	0.	15.	0	66.8152
53		0.5591	0.	1.	1	12.1537
45		0.0762	0.	2.	0	2.6565
14		8.9429	0.	19.	2	147.4099
16		1.0000	0.	1.	1	16.5746

            SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
45		1	0.8987	65.0112	556.3557
62		1	0.9869	14.0977	1395.2598
13		1	0.9229	81.3306	1368.8542
70		1	0.0	380.0037	0.0
71		1	0.5977	380.0037	409.1404
51		1	0.4062	223.5811	153.8564

            BLOCKED TIME PER UNIT TIME

SERVER	LABEL	AVE.	LONGEST PERIOD BLOCKED
70		0.5284	19.9863

            NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
25		0.0
47		0.0
6		0.0
45		0.0

APPENDIX F (CONT.)
(second run)

GERT SIMULATICN PROJECT THESES   BY CORB
               DATE 1 / 7 / 1979

RESULTS FOR RUN   1

ELAPSED TIME FOR RUN =   3000.0000

NODE STATISTICS

NODE	LABEL	AVE.	NO OF OBS.	TYPE OF STATISTICS
10		50.7774	177.	I
62		116.9624	219.	I
59		89.6510	66.	I
61		129.5703	15.	I
52			NO VALUES RECORDED	
67		236.4090	171.	I

NUMBER IN Q-NODE   ** WAITING TIME **
IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
25		1.7701	0.	7.	0	26.4153
47		4.5348	0.	12.	6	61.5580
6		3.8772	0.	13.	9	52.1601
49		3.0958	0.	15.	0	66.8152
53		0.5591	0.	1.	1	12.1537
45		0.0762	0.	2.	0	2.6565
14		9.9429	0.	19.	2	147.4099
16		1.0000	0.	1.	1	16.5746

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
45		1	0.8987	65.0112	556.3557
62		1	0.9869	14.0977	1395.2598
13		1	0.9229	81.3306	1368.8542
70		1 SERVER NEVER USED			
71		1	0.5977	380.0037	409.1404
51		1	0.4062	223.5811	153.8564

BLOCKED TIME PER UNIT TIME

SERVER	LABEL	AVE.	LONGEST PERIOD BLOCKED
70		0.5284	19.9863

NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
25		0.0
47		0.0
9		0.0
45		0.0

(second run)

NODE	TRANSACTION PASSAGES
1	601
2	131
3	33
4	765
5	444
6	214
8	213
9	104
10	177
11	560
12	113
13	182
14	180
15	10
16	180
17	360
18	180
24	1
25	201
41	193
42	573
43	99
44	26
45	86
47	215
49	139
50	86
51	86
53	137
54	214
55	214
56	131
57	136
58	25
59	66
60	71
61	15
62	219
67	171
99	180

APPENDIX F (CONT.)

(second run)

PRINTOUT OF ONGOING ACTIVITIES
AT   3000.00

ACTIVITY END TIME	END MODE	ACTIVITY NUMBER
3001.88	8	13
3003.94	11	46
3004.39	10	17
3005.00	1	1
3006.15	11	46
3008.00	2	3
3009.09	54	62
3009.53	62	65
3009.70	62	72
3011.72	11	46
3012.97	11	46
3016.94	57	71
3050.16	67	98
3050.16	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3058.52	67	98
3069.00	3	5
**********	62	74
**********	54	54
**********	62	75
**********	62	54
**********	54	54
**********	54	54
**********	54	55
**********	62	75
**********	54	54
**********	62	74
**********	62	65
**********	54	54
**********	62	75
**********	62	74
**********	54	55
**********	54	54
**********	54	54
**********	54	54
**********	54	75
**********	54	54
**********	54	54
**********	54	55
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	54
**********	54	55
**********	54	55
**********	54	55
**********	54	55
**********	52	55
**********	52	55
**********	52	55
**********	52	55
**********	52	55
**********	52	55
**********	52	55
**********	52	55

APPENDIX F (CONT.)
(second run)

GERT SIMULATION PROJECT THESES   BY COBB
DATE 1/ 7/ 1979

FINAL RESULTS FOR   1 SIMULATIONS

AVERAGE NODE STATISTICS

NODE LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	STAT TYPE
10	1.0000	90.7774	0.0	0.0	90.7774	90.7774	1
62	1.0000	116.9624	0.0	0.0	116.9624	116.9624	1
59	1.0000	89.6510	0.0	0.0	89.6510	89.6510	1
61	1.0003	129.5703	0.0	0.0	129.5703	129.5703	1
52		NO VALUES RECORDED					
67	1.0000	236.4090	0.0	0.0	236.4090	236.4090	1

AVERAGE NUMBER IN Q-NODE

NODE LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.
25	1.7701	0.0	0.0	1.7701	1.7701	26.4193	0.0	0.0		7.0000
47	4.5348	0.0	0.0	4.5348	4.5348	61.5580	0.0	0.0		12.0000
48	3.8772	0.0	0.0	3.8772	3.8772	52.1601	0.0	0.0		13.0000
53	3.0958	0.0	0.0	3.0958	3.0958	66.8152	0.0	0.0		11.0000
14	0.5591	0.0	0.0	0.5591	0.5762	12.1537	0.0	0.0		1.0000
16	8.5429	0.0	0.0	8.5429	6.5429	147.4065	0.0	0.0		15.0000
	1.0000	0.0	0.0	1.0000	1.0000	16.5746	0.0	0.0		1.0000

AVERAGE SERVER UTILIZATION

SERVER LABEL	NO. PARALLEL SERVERS	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.
45	1	0.8987	0.0	0.0	0.8987	0.8987	65.0112				256.3557
62	1	0.9869	0.0	0.0	0.9869	0.9869	14.0977				1365.2558
13	1	0.9229	0.0	0.0	0.9229	0.9229	81.3306				1365.8542
70	1	0.5977	0.0	0.0	0.5977	0.5977	380.0037				409.1404
51	1	0.4062	0.0	0.0	0.4062	0.4062	223.5811				153.6564

AVERAGE BLOCKED TIME PER UNIT TIME

SERVER LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.			
70	0.5284	0.0	0.0	0.5284	0.5284			19.9863

AVERAGE NO. BALKING PER UNIT TIME

NODE LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.
25	0.0	0.0	0.0	0.0	0.0
47	0.0	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.0	0.0

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APPENDIX G

INTERFACE ROUTINE

(model)

```
      FUNCTION UF(IFN)
      COMMON/GVAR/NDE,NFTBU(100),NREL(100),NRELP(100),
     1 NREL2(100),NRUN,NRUNS,NTC(100),PARAM(100,4),TBEG,TNOW
      DIMENSION ATT(11)
C******USER FUNCTIONS FOR INTERFACE ROUTINE
      UF=0.
      GO TO (1,2,3,4,5,6,7),IFN
    1 READ(3,100) TTNOW,A7,A9,A1,A2,A3,A4,A5,A6,A8
  100 FORMAT(2X,F4.0,2(1X,F5.0),1X,F3.0,1X,F4.0,2(1X,F2.0),
     12X,3(F2.0,1X))
      NN=NN+1
      IF(A7.LT.0.0) UF=1.
      RETURN
    2 ATT(1)=A1
      ATT(2)=A2
      ATT(3)=A3
      ATT(4)=A4
      ATT(5)=A5
      ATT(6)=A6
      ATT(7)=A7
      ATT(8)=A8
      ATT(9)=A9
      ATT(10)=TTNOW
      ATT(11)=0.0
      CALL PTIN(2,0.0,TNOW,ATT)
      UF=.05
      RETURN
    3 IF(NREL(14).EQ.58) UF=58
      RETURN
    4 ALAST=0.0
      NN=0
      NT=0
      RETURN
    5 AT10=GATRB(10)
      AT9=GATRB(9)
      UF=AT10-AT9
      RETURN
    6 NT=NT+1
      AT9=GATRB(9)
      UF=AT9-ALAST
      ALAST=AT9
      WRITE(6,361) TNOW,UF
  361 FORMAT(1X,F6.1,'--SIMULATION TIME',3X,F5.1,'--AS DIFF')
C******USED TO CHECK SEQUENCING ROUTINE
      RETURN
    7 AT1=GATRB(1)
      AT2=GATRB(2)
      AT3=GATRB(3)
      AT4=GATRB(4)
      AT5=GATRB(5)
      AT6=GATRB(6)
      AT7=GATRB(7)
      AT8=GATRB(8)
      AT9=GATRB(9)
      AT10=GATRB(10)
      WRITE(6,360)AT1,AT2,AT3,AT4,AT5,AT6,AT7,AT8,AT9,AT10
  360 FORMAT(1X,10(F6.1,1X))
      RETURN
      END
```

```
*** INPUT CARDS ***

GEN,COBB,THESES,01,07,1979,,17,185,1000,1,F,,11*
SCU,99,0,1*
VAS,99,10,UF,4*
SCU,1,0,1,A,M*
VAS,1,11,UF,1*
ACT,1,1,UF,2,1,,,A11.EQ.0.*
SIN,38,1,1,,I*
ACT,1,38,,,2,,,A11.EQ.1.*
REG,2,1,1,F*
REG,3,1,1,F*
ACT,2,3,,,3,,,A6.EQ.1*
SIN,5,1,1,,I*
ACT,3,5,,,4,,,A3.EQ.1*
SIN,6,1,1,,I*
ACT,3,6,,,5,,,A3.EQ.2*
SIN,7,1,1,,I*
ACT,3,7,,,6,,,A3.EQ.3*
SIN,8,1,1,,I*
ACT,3,8,,,7,,,A3.EQ.4*
SIN,9,1,1,,I*
ACT,3,9,,,8,,,A3.EQ.5*
SIN,10,1,1,,I*
ACT,3,10,,,9,,,A3.EQ.6*
SIN,11,1,1,,I*
ACT,3,11,,,10,,,A3.EQ.7*
SIN,12,1,1,,I*
ACT,2,12,,,13,,,A6.EQ.3*
SIN,13,1,1,,I*
ACT,2,13,,,19,,,A6.EQ.6*
REG,4,1,1*
VAS,4,11,CO,58*
ACT,2,4,,,12,,,A6.EQ.2*
QUE,14,0,,D,S/S,(10)26*
ACT,4,14,,,14*
SOU,24,0,1,A,M*
VAS,24,11,UF,3*
ACT,24,24,CO,1,,24*
CUE,25,0,1,D,(10)26*
ACT,24,25,,,15,,,A11.EQ.58*
REG,27,1,1*
ACT,27,25,,,16*
QUE,15,0,,D,F*
VAS,15,11,UF,7*
MAT,26,11,14/15,25/27*
QUE,28,0,,D,B/1*
ACT,15,28,UF,6,19*
QUE,29,0,1,D,,8*
ACT,28,29,,,17*
REG,30,1,1,F*
ACT,29,30,UF,5,18*
SIN,31,1,1,,I*
ACT,30,31,,,20,,,A3.EQ.1*
SIN,32,1,1,,I*
ACT,30,32,,,21,,,A3.EQ.2*
SIN,33,1,1,,I*
ACT,30,33,,,22,,,A3.EQ.3*
SIN,34,1,1,,I*
ACT,30,34,,,23,,,A3.EQ.4*
SIN,35,1,1,,I*
ACT,30,35,,,24,,,A3.EQ.5*
SIN,36,1,1,,I*
ACT,30,36,,,25,,,A3.EQ.6*
SIN,37,1,1,,I*
ACT,30,37,,,26,,,A3.EQ.7*
FIN*
```

GERT SIMULATION PROJECT THESES   BY COBB
          DATE 1/ 7/ 1979

FINAL RESULTS FOR FIRST SIMULATION

TOTAL ELAPSED TIME =   1000.0000

NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO OF OBS.	STAT TYPE
38		0.0	0.0	1.	I
5				NO VALUES RECORDED	
6				NO VALUES RECORDED	
7				NO VALUES RECORDED	
8				NO VALUES RECORDED	
9				NO VALUES RECORDED	
10				NO VALUES RECORDED	
11		0.0	0.0	55.	I
12		0.0	0.0	19.	I
13		0.0	0.0	52.	I
31		339.7300	49.7745	5.	I
32		297.5300	122.5947	5.	I
33		413.8501	0.0	1.	I
34		294.4500	124.0261	6.	I
35		313.7000	0.0	1.	I
36				NO VALUES RECORDED	
37		466.0054	213.3669	24.	I

NUMBER IN Q-NODE   ** WAITING TIME **
                                           IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
14		0.2378	0.	58.	0	4.0952
25		0.9900	0.	1.	1	16.7756
13		29.2260	0.	57.	13	503.8965
28		0.8230	0.	5.	0	19.7045
29		0.5430	0.	1.	1	12.3409

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
19		1	0.9900	10.0000	990.0000
17		1	0.0	263.0000	0.0
18		1	0.5970	235.0000	523.0000

BLOCKED TIME PER UNIT TIME

SERVER	LABEL	AVE.	LONGEST PERIOD BLOCKED
17		0.4550	17.0000

NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
25		0.0

APPENDIX G (CONT.)

(output)

NODE	TRANSACTION PASSAGES
1	185
2	184
3	55
4	58
11	55
12	19
13	52
14	58
15	45
24	1001
25	58
26	116
27	59
28	44
29	43
30	42
31	5
32	5
33	1
34	6
35	1
37	24
38	1
99	1

PRINTOUT OF ONGOING ACTIVITIES
AT   1000.00

ACTIVITY END TIME	END NODE	ACTIVITY NUMBER
1001.00	24	24
1007.00	30	18
1128.00	28	19

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APPENDIX G (CONT.)
(output)

```
***RESULTS FOR RUN    1***

ELAPSED TIME FOR RUN =   1000.0000
```

NODE STATISTICS

NODE	LABEL	AVE.	NO. OF OBS.	TYPE OF STATISTICS
38		0.0	1.	I
5				NO VALUES RECORDED
6				NO VALUES RECORDED
7				NO VALUES RECORDED
8				NO VALUES RECORDED
9				NO VALUES RECORDED
10				NO VALUES RECORDED
11		0.0	55.	I
12		0.0	19.	I
13		0.0	52.	I
31		339.7300	5.	I
32		257.5300	5.	I
33		513.8501	1.	I
34		254.4500	6.	I
35		313.7000	1.	I
36				NO VALUES RECORDED
37		466.0054	24.	I

NUMBER IN Q-NODE   ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
14		0.2378	0.	58.	0	4.0992
25		0.9900	0.	1.	1	16.7756
15		25.2260	0.	57.	13	503.8965
28		0.8230	0.	5.	0	18.7045
29		0.5430	0.	1.	1	12.3409

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
19		1	0.9900	10.0000	990.0000
17			SERVER NEVER USED		
18		1	0.5970	235.0000	523.0000

BLOCKED TIME PER UNIT TIME

SERVER	LABEL	AVE.	LONGEST PERIOD BLOCKED
17		0.4550	17.0000

NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
25		0.0

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GERT SIMULATION PROJECT T-FSES   BY COBB
DATE 17/ 7/ 1979

FINAL RESULTS FOR   1 SIMULATIONS

AVERAGE NODE STATISTICS

NODE LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	STAT TYPE
38	1.0000	NO VALUES RECORDED	0.0	0.0	1.	0.0	0.0	I
5		NO VALUES RECORDED						
5		NO VALUES RECORDED						
8		NO VALUES RECORDED						
9		NO VALUES RECORDED	0.0			0.0	0.0	
	1.0000	0.0	0.0	0.2378	1.	0.0	0.0	
	1.0003	0.0	0.0	0.9900	1.	0.0	0.0	
	1.0000	339.7300	0.0	29.2260	1.	339.7300	339.7300	
	1.0000	257.5300	0.0	0.8230	1.	257.5300	297.5300	
	1.0000	512.8501	0.0	0.5430	1.	512.8501	512.8501	
	1.0000	294.4500	0.0		1.	294.4500	294.4500	
	1.0000	313.7000	0.0		1.	313.7000	313.7000	
37	1.0000	NO VALUES RECORDED 466.0054	0.0		1.	466.0054	466.0054	I

AVERAGE NUMBER IN Q-NODE   **NUMBER IN Q-NODE**

NODE LABEL	AVE.	STD.DEV.	SD OF AVE	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	MAX.
14	0.2378	0.0	0.0	0.2378	0.0	0.0			58.0000
15	0.9900	0.0	0.0	16.7796	0.0	0.0			51.0000
22	29.2260	0.0	0.0	503.8965	0.0	0.0			57.0000
28	18.8230	0.0	0.0	18.7045	0.0	0.0			1.0000
29	0.5430	0.0	0.0	12.3409	0.0	0.0			

AVERAGE WAITING TIME

	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.
	4.0952	0.0	0.0		
	16.7796	0.0	0.0		
	503.8965	0.0	0.0		
	18.7045	0.0	0.0		
	12.3409	0.0	0.0		

AVERAGE SERVER UTILIZATION

SERVER LABEL	NO. PARALLEL SERVERS	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
16	1	0.9900	0.0	0.0	1.	0.9900	0.9900
18	1	0.5970	0.0	0.0	1.	0.5970	0.5970

EXTREME VALUES

	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY
	10.0000	590.0000
	265.0000	0.0
		523.0000

AVERAGE BLOCKED TIME PER UNIT TIME

SERVER LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
17	0.4550	0.0	0.0	1.	0.4550	0.4550

BLOCKED TIME OF SERVER

	LONGEST PERIOD BLOCKED
	17.0000

AVERAGE NO. BALKING PER UNIT TIME

NODE LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
25	0.0	0.0	0.0	1.	0.0	0.0

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